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Energy Efficiency Retrofitting of Buildings
Challenges and Methods
Research Program in Hubei Province, China

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Foreword

The Agence Française de Développement (AFD) committed to developing intellectual cooperation programs at the request of the Chinese authorities when it signed the agreement allowing it to operate in China. It asked its Research Department to develop the first of such programs. This program, the methodology for which is the subject of this book, falls under the theme of "sustainable development: the contribution of official development assistance (ODA) to the production of global public goods." It arose from a request by the Chinese authorities in Hubei Province[1] that had been expressed during an identification visit in February 2006. The request dealt with the energy efficiency of existing buildings. Indeed, saving energy is an important line of work in the 11th Five-Year Plan (2005–2010) that set particularly ambitious targets to cut energy intensity by 20%, and assigned energy efficiency targets for the major cities and a number of pilot provinces.

In 2006, energy efficiency in existing buildings was still a somewhat unfamiliar notion in Hubei Province. The request addressed to AFD by the municipal and provincial authorities covered several aspects of this sector, and in particular: *(i)* simple technical aspects (how do you conduct an energy audit of a building?); *(ii)* current practices in developed countries (what energy efficiency policies and what institutions have been set up, what technical and financial tools are used, what has the outcome been?); and finally, *(iii)* how do you develop a large-scale energy efficiency policy for existing public buildings (what should be done, how are challenges to be identified, what strategies should be utilized?).

To fulfill this specific request and its accompanying operational targets, AFD proposed an approach based on: *(i)* the establishment of multi-year bi-directional cooperation fostering mutual acquisition and knowledge, *(ii)* the joint elaboration of a methodology (by Chinese teams and French teams) based on the content and goals of the desired program, *(iii)* the design of an open research program that would evolve depending on the progress made and that could include specific training, *(iv)* co-financing of this program (each party funding its own teams), and finally, *(v)* the formation of a multi-disciplinary team composed of academics, engineers, financiers and representatives of various provincial and municipal administrations.

[1] In mainland China, there are 23 provinces, five autonomous regions for national minorities, and four direct-controlled municipalities (Beijing, Shanghai, Tianjin and Chongqing), which are on the same hierarchical level.

This approach was pioneering and innovative for several reasons:

- the team that was set up consisted of members from very different sectors not used to communicating or working with each other yet, in spite of this, it was open-minded when other actors joined the program (depending on their role in the chain of energy efficiency or the complementarity of their work with the work undertaken in the program);
- the program's diversity including, alongside the analysis and research components, a training component that was not limited to team members alone but was open to other actors from operational milieus, universities, and concerned offices located in other cities in the province;
- the production of real techno-economic feasibility studies for a "full-scale" experimental program capable of being implemented during the program; and
- the organization of reflection workshops with the various actors involved in energy efficiency (banks, administrative offices, financial services, etc.) and discussion workshops to present complementary work (and international experience) to the team and the results of the team's research to their peers and other actors.

To comply with the operational logic desired by the Chinese partners, the program's Chinese team, very close to action-research, was formed to favour the involvement of municipal, provincial and national decision-makers in the program, along with people from the technical offices concerned in the public sector as well as the private sector, such as Energy Service Companies (ESCOs) or banks.

This program was elaborated with the technical and financial support of the Agence de l'Environnement et de la Maîtrise de l'Énergie (ADEME) and of high-level independent French experts. To attain partial objectives, research agreements were signed with the Swiss Federal Institute of Technology Zurich and the Fraunhofer Institut für System und Innovationforshung Karlsruhe, and a partnership was forged with the International Energy Agency (IEA).[2]

Finally, this program was developed in synergy with the actions undertaken in this field in Harbin (Heliong Jiang Province) in the early 2000s by the French Global Environment Facility (FGEF).

[2] See AFD and IEA (2008); most of this document was later translated into Chinese.

This document aims to explain the methodology used during the three years of the program. This methodology can *(i)* describe the existing building stock, *(ii)* determine the techno-economic challenges of an energy efficiency retrofitting program in public buildings at different scales (provincial capital, Yangtze province and climate region), *(iii)* determine the most appropriate technical solutions given the local climate, and *(iv)* evaluate the most relevant institutional and financial systems for the Chinese context.

This document does not emphasize the difficulties arising from cultural differences that needed to be overcome to successfully complete the program.[3] Cultural differences can manifest themselves in a fragile relationship in which the expression of a simple courtesy may be perceived in the other culture as an unconscionable insult, with the risk of making one's interlocutor lose face and putting a definitive end to the relationship. These differences also express themselves in how problems are tackled, making discussions more complex: in one culture, action is based on a Cartesian strategy that had previously identified similar objectives and prioritized actions; in the other, it is based on the completion of the action identified as being most urgent, the outcome of which will be measured and then adjusted based on an assessment.

The chemistry is delicate, and trust was built as the program advanced. The rule is simple and underlies all balanced relationships: one must know how to listen, be patient, and above all, sense expectations, be able to meet expressed needs, not make promises one cannot keep, not deceive, etc. Another, undoubtedly more serious difficulty that needed to be overcome was getting very diverse teams made up of academics, bankers, engineers, civil servants, etc. to communicate with each other and work together.

The experience acquired in the field of intercultural management could fill a book of its own, but this was not the subject of our study. These elements serve to remind the reader that the possibility of replicating the program does not by a long shot rely solely on mastery of the method and technical aspects.

This program's results were assessed at national level by the Chinese Ministry of Housing and Urban and Rural Development (MOHURD). Following this assessment, the Ministry decided to join the conference presenting the results, which was held in Wuhan from May 12–13, 2009. (The conference proceedings were published by the AFD in October 2010.[4])

[3] Here, we must honor and thank Mr. Liu Yazong, energy efficiency expert, equally at home in Chinese and western cultures who, throughout the project, played the role of major interface on the technical and cultural levels.

[4] See AFD (2010), Implementing Large-Scale Energy Efficiency Programs in Existing Buildings in China.

Finally, let us specify that, as part of the research program, the technical teams produced feasibility studies on energy efficiency upgrading of a number of buildings with the aim of fostering the completion of a demonstration program. The goal of this demonstration program was the on-site, full-scale validation of the research program's results in terms of energy efficiency and investment costs. These technical teams continued their work and extended the techno-financial audits and feasibility studies to many other municipal buildings, consolidating a program of nearly 700,000 sq. m. of buildings for energy efficiency retrofitting, thereby encouraging the municipal leaders to look for the funding to conduct the retrofits.

The local AFD representative in Beijing, to whom the continuation of this program was entrusted (after the Wuhan conference), naturally steered the continuation toward the financing of this operation. This was not the aim of the initial research program, which focused more on the financial mechanisms that could enable an energy efficiency program to shift to the large scale, but this re-orientation perfectly illustrates the dynamic created during the program and reveals the interest and success of the method.

Contents

Introduction

Introduction

In 2008, energy consumption in buildings in the residential and tertiary sectors accounted for 33% of final energy consumption worldwide, which was itself of the order of 8 billion tons of oil equivalent (toe), ahead of industry (29%) and transport (27%). In this same building sector, electricity consumption accounted for 53% of total electricity consumption worldwide. Leading the major sectors of activity in energy consumption, and more specifically electricity consumption, the building sector consequently is a favoured target for energy efficiency policies, which have become indispensable in all economies, given the constraints imposed by energy security and climate change.

Implementing energy efficiency in buildings involves three categories of actions:

- building new buildings that are as energy efficient as possible while providing occupants with the necessary comfort;
- energy efficiency retrofitting of existing buildings with the same goal; and
- using energy efficient equipment and appliances inside buildings.

One can instantly see that, to be successful, such an undertaking requires multiple technical innovations compared to current building design practices, construction materials and equipment, the quality of initial construction and maintenance, etc. The technical dimension is accompanied by precise economic cost evaluations according to the technical choices made and the desired level of improvement in energy performance, as well as the energy, environmental, economic and social benefits of the work and programs envisaged. Finally, all this is completed by a search for the most suitable ways to finance this new type of operation.

Paradoxically, and because it is in this field that we see the most advanced innovations, building more energy efficient buildings than their predecessors was proved to be the easiest and least expensive option. In countries that have successfully negotiated this shift in new construction, the steps taken were a combination of thermal regulations on new buildings (made stricter in a progressive and scheduled fashion), ongoing consultation with partners (architects, consultancy firms, construction firms, manufacturers of materials and equipment), training programs, research and development, and industrial policy to ensure that all the "ingredients" necessary to comply with thermal regulations and building codes were available on the market.

The energy efficiency retrofitting of existing buildings is another matter, one that is more complex to implement and more difficult to organize. Of course, it has benefited greatly from technical progress in new construction, from design to building techniques, materials and equipment. But it also raises difficulties of a different nature because of the extreme diversity of existing buildings from all standpoints: period of construction, quality of materials and construction methods, categories of use (particularly in the tertiary sector), and perhaps above all occupation and/or legal status and administrative situation (owner, renter, public, private, lack of regulations, etc.). As a result, the technical operations one can envisage for an energy efficiency retrofit are often technically complex; one must make difficult trade-offs in the degree of retrofitting for financial reasons; and one must take into account a long and difficult economic, social, administrative and financial "learning period." Thus, while thermal regulations on new construction were established in the various countries following roughly the same process, the method for elaborating thermal retrofitting programs demands greater attention to local economic, social and institutional situations.

For a long time, public authorities and private actors alike shied away from these difficulties and, in many cases, it must be admitted that the relatively low cost of energy and the illusion that this situation would continue indefinitely quite simply encouraged them to do nothing in this sector. In addition, retrofitting buildings has always been considered as less "noble" than new construction. However, given the inevitable constraints both in regard to energy and the climate, retrofitting existing buildings is becoming necessary because of the size of the building stock compared to the amount of new construction each year in the market (the proportions of which obviously vary from country to country). Even in high-growth emerging countries where there is a lot of new construction, the building stock offers considerable energy saving potential (because the stock was built at a time when "energy guzzling" buildings were built due to a lack of means or foresight). One can now see a fairly widespread awareness that building energy-efficient new buildings is of course a good thing but that ultimately not enough progress might be made if one continues year after year to wear around one's neck the "energy millstone" of an old building stock that, while potentially useable, will continue to consume large amounts of energy. Beyond this "obligation to act," the innovative and economically and socially interesting nature of energy efficiency retrofitting of buildings is felt especially strongly in large emerging countries, most of which have until now only tackled energy performance in new buildings on a large scale.

China's case is particularly significant: such a shift is important for the country and its own economic and environmental targets, as well as for the rest of the world because of the magnitude of its energy consumption and greenhouse gas emissions. Indeed, in 2008, *per capita* primary energy consumption in China was 1.6 toe (compared to 3.6 toe in the European Union and 7.9 toe in the United States). But, with a population of 1.3 billion, China's total primary energy consumption was 2 billion toe or 17% of world consumption, on par with the United States. Given that the residential and tertiary building sectors are responsible for 30% of final consumption in China, and given that this figure is growing sharply, one can understand the scope of the challenge.

The largest share of energy consumption in buildings in China is devoted to thermal comfort: heating in the north and centre, and cooling in the centre and south. As a general rule, consumption in buildings is rising rapidly because of the rapid growth of the building stock, aspirations to greater comfort, and growing use of domestic and professional appliances and equipment that use energy (household appliances, audiovisual equipment, computers), especially in urban areas.

Important policy guidelines were established in the country to improve energy efficiency in new buildings, in particular through the promulgation and increasing application of new and ambitious thermal regulations on buildings, set at the national level and adjusted at the provincial level, based on weather conditions. But, although potential gains in energy efficiency are considerable in existing buildings, efforts in this sector are still relatively small because of a series of technical, economic, institutional and financial difficulties.

The objective of the research program conducted jointly by the Hubei Province Construction Department and the AFD Research Department consisted of establishing the necessary framework for energy efficiency retrofitting of existing buildings in Hubei, notably as concerns the proposal of new and innovative financial mechanisms that would enable large-scale implementation. The goal was, in close collaboration between the Chinese and French partners, to seek to eliminate or at least reduce the financial constraints that weigh on energy efficiency retrofit investments – the major obstacle to the expansion of this activity – and more generally to create all the conditions necessary for implementation. The Hubei Province Construction Department had decided to work in priority on energy efficiency retrofitting of large buildings in the tertiary sector (both public and private) so the research program focused mainly on these buildings.

The combination of a team of experts from AFD, managers and staff from the administration, and academic teams from the province made it possible to conduct applied research with an awareness of overall stakes, in parallel with the objective of concrete achievements.

The research program methodology elaborated collectively, addresses a specific category of buildings in a specific province in China, but it can be applied to other categories of buildings (housing, for instance), in other provinces of the country, and in other countries thanks to the logic of its components and its organization. Indeed, the very structure of the method elaborated specifically allows for the natural inclusion of specific characteristics whose importance we emphasized above. Insomuch as this was applied research, whose nature and goal of concrete application are decisive, it would have been of limited interest to present readers with a "theoretical" methodology. However, the step-by-step illustration of the methodology through its application to a real case of considerable importance makes the explanation of the methodology more educational, more interesting, and more convincing. While the research program focused on China and more specifically tertiary buildings in the city of Wuhan, this document describes a methodological framework that can be applied to other regions and other countries.

The originality of the methodology thus elaborated comes largely from including, from the start of the research, in the research program's principles and organization the complementarity and coordination of various skills and, therefore, different partners who would contribute to implementing energy efficiency retrofitting projects and programs.

Indeed, the classic approach consists of elaborating a series of (technical, economic, social, institutional and financial) questions and answering them separately and "sequentially" in this order and over time, from the acquisition of basic data to the reflections on financial arrangements.

In this research approach, however, the requirement of complementarity made it so that the expert groups skilled in the various issues – each group bringing together the partners concerned – worked in parallel and their progress and results interacted with the progress and results of the other groups at each stage and, as far as possible, they advanced together in the search for an optimal overall solution in light of the constraints attached to each of the issues. Thus, the method does not consist of exploring the various possible solutions and choosing the best in each area, but of progressing in an interactive fashion among the different disciplines, in an iterative fashion over time (this or that result requiring more specific exploration in a specific area), and in an ongoing fashion because while the research program itself strictly speaking will end at a given point in time, the concrete implementation of energy efficiency retrofitting projects and programs will provide new elements that in turn will modify choices in this or that area.

Presenting a research program in written form requires one to handle the various issues that were addressed in a linear fashion, and calls for one to describe the overall context and challenges of such a program. It is therefore difficult to portray the "back and forth" and hesitations in the research itself, as well as the "phasing" of the research between periods of progress in this or that field and the periods of synthesis, exchange, re-adjustment of tasks, renewal of explorations on new or old questions – all things that also make up the wealth of the research but are by necessity "smoothed over" to a large degree in a document that seeks to be logical and understandable.

The document presented herein therefore groups the program's progression and results in five sections that seemed to us to be the most logical for readers to follow and understand the method:

- 1: energy challenges in buildings worldwide and in China, illustrated by a comparison of two large ensembles of comparable population but very different economic levels: China and the countries in the Organisation for Economic Co-operation and Development (OECD).
- 2: presentation of the methodology used in the research program on energy efficiency retrofitting of buildings and its components, principles and organization. These elements can be seen as independent of any one specific program (such as the one in Hubei Province) and applicable in other national or regional contexts.
- 3: detailed presentation of the technical and economic components in the elaboration of building energy efficiency retrofitting programs, from a typology of building energy consumption (using the example of the city of Wuhan) to the assessment of stakes and impacts of large-scale operations. This chapter covers relatively complex technical questions, some elements of which are given in the appendices. This allows readers, even non-specialists, to clearly understand the progression of an approach in which each task is crucial and the high scientific level and precision of the instruments and studies that make it possible to ensure the success of a large-scale policy of energy efficiency retrofitting of buildings. Let us recall, borrowing a quote from Descartes, "the devil is in the details." In other words, it is by following each phase of the method step by step that one can fully grasp the quality and versatility of the approach. Examples are presented in the appendices to the main document.

- 4: analysis of the interplay among actors involved in the decision-making, organizational and financing process for energy efficiency retrofitting projects. Based on the example of the Hubei program, this chapter shows the opportunities and barriers encountered when implementing such programs. It also shows the importance of institutional, organizational, social and financial issues that require good knowledge of the national, provincial and local situation to be addressed.
- 5: assessment of adaptation conditions for existing financial mechanisms and the development of complementary systems devoted to financing programs. It is understood that the aim is first to obtain clear understanding, *via* discussions with financial partners, of what "exists" in terms of financing and, once analyzed and utilized, propose – noting the difficulty adapting traditional financial tools to this new type of activity – innovative methods that take their inspiration from international experience and are adapted to local conditions based on dialogue with these same partners.

The conclusion emphasizes the most striking points of the approach and the results obtained, and comments on its strengths and weaknesses.

Part One

1. China in the world: The stakes involved in energy consumption in buildings

Preamble

The research program on energy efficiency retrofitting of buildings presented in this document took place in Hubei Province, China, and focused more specifically on buildings in the provincial capital, Wuhan. Whatever the size of an envisaged program, particularly if it is seen as a pilot program for large-scale operations (as was the case here), it is of vital importance to assess the energy stakes for the building sector in the country concerned (if only to help increase awareness among policy makers and thereby facilitate their decision making). In this first chapter, we place these stakes for China in the global context, based on a comparison between China and OECD countries (a comparison justified by the similar population levels in these two entities).

1.1. China's energy consumption in the world

In a world with a population of 6.67 billion people (OECD, 2008), China – the most heavily populated "emerging" country (pop. 1.33 billion) – and the OECD countries – a group of "developed" countries (pop. 1.19 billion) make up two entities of roughly the same size in terms of population. It is interesting to compare energy consumption from the standpoint of the final consumer.

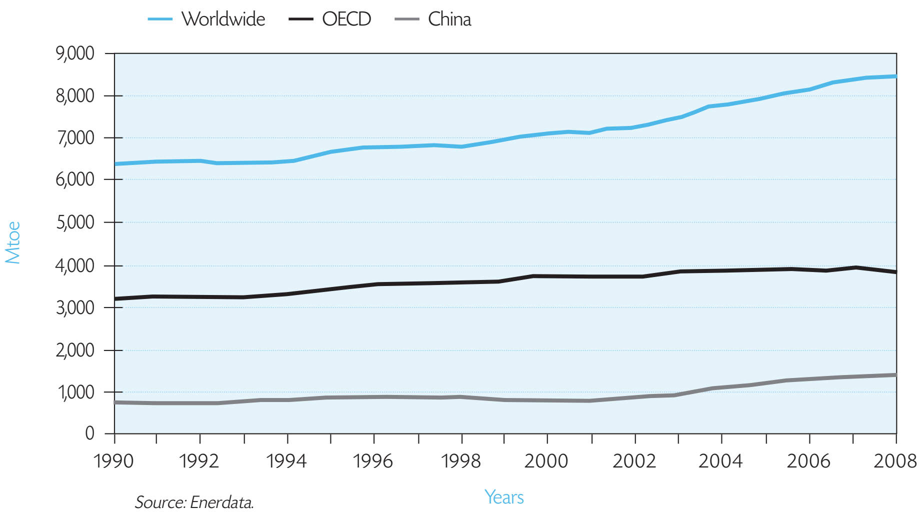
1.1.1. *Final energy consumption*

Total and *per capita* energy consumption

Final energy consumption corresponds to energy products that are delivered to consumers: oil products, gas, coal, heat, electricity, biomass (wood used for heating). The consumer sectors are industry, transportation, agriculture, residential and tertiary (energy consumed in buildings in these two sectors). Final consumption also covers consumption of energy products, mainly oil products and gas consumed for non-energy purposes (notably in chemistry to produce plastics and fertilizer).

With consumption of 3,830 Mtoe, the OECD accounts for 45.4% of final energy consumption worldwide (8,431 Mtoe) while China, with 1,403 Mtoe, accounts for only 16.6%.

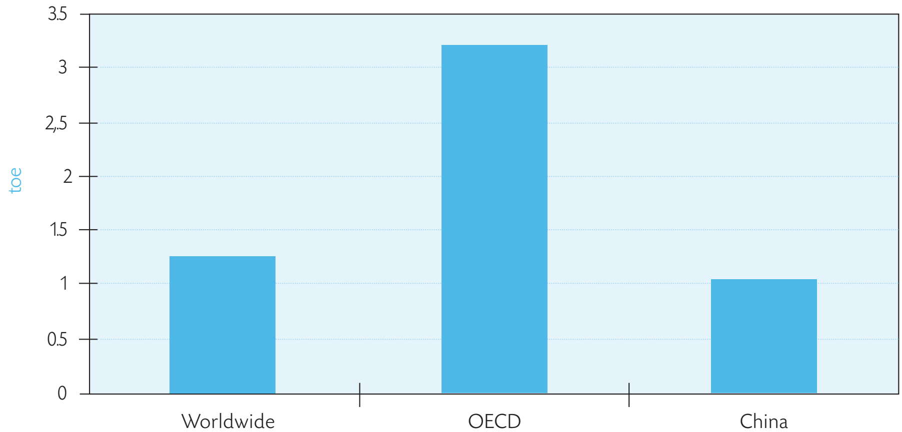
Figure 1 *Evolution of Final Energy Consumption Worldwide, in OECD Countries, and in China, from 1990 to 2008 (in Mtoe)*



Source: Enerdata.

The changes in consumption, shown in Figure 1, illustrate the "emerging" nature of the Chinese economy: the very strong growth in gross domestic product (GDP) since 2000 resulting in a clear increase in energy consumption. This gap is confirmed by the comparison of *per capita* final energy consumption, shown in Figure 2.

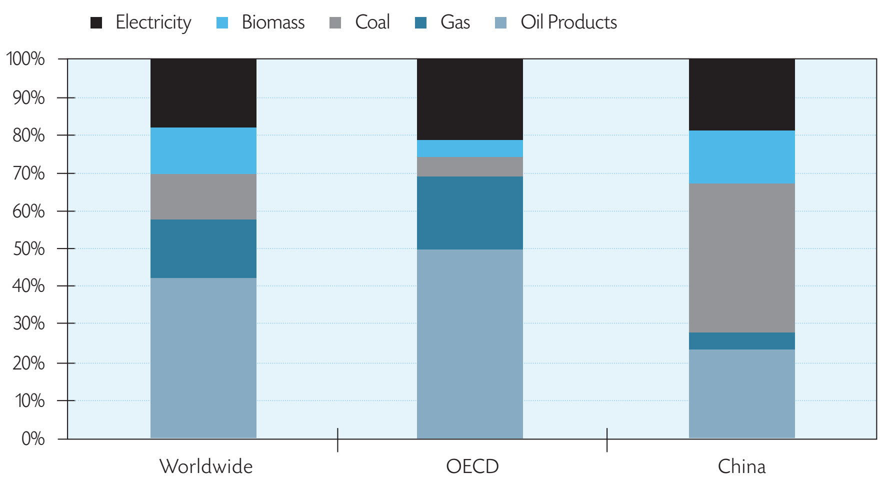
Figure 2 *Per Capita Final Energy Consumption Worldwide, in OECD Countries, and in China, in 2008 (in toe)*



Source: Enerdata.

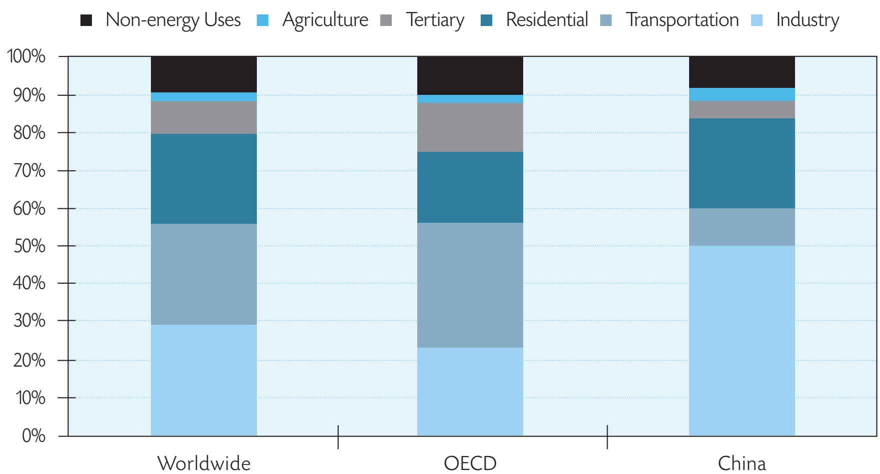
Structure of final energy consumption by product and by sector

Figure 3 *Final Energy Consumption by Product Worldwide, in OECD Countries, and in China, in 2008 (in %)*



Source: Enerdata.

Figure 4 *Final Energy Consumption by Sector Worldwide, in OECD Countries, and in China, in 2008 (in %)*



Source: Enerdata.

Figures 3 and 4 show that the structure of final energy consumption is considerably different in China and OECD countries. In the breakdown by product, China differs from the OECD countries in the high proportion of coal used directly as a final energy product whereas, in OECD countries, final coal consumption is low: most coal is used to produce electricity. Electricity consumption accounts for approximately 20% of final energy consumption in all cases (18% worldwide and in China, and 21% in OECD countries).

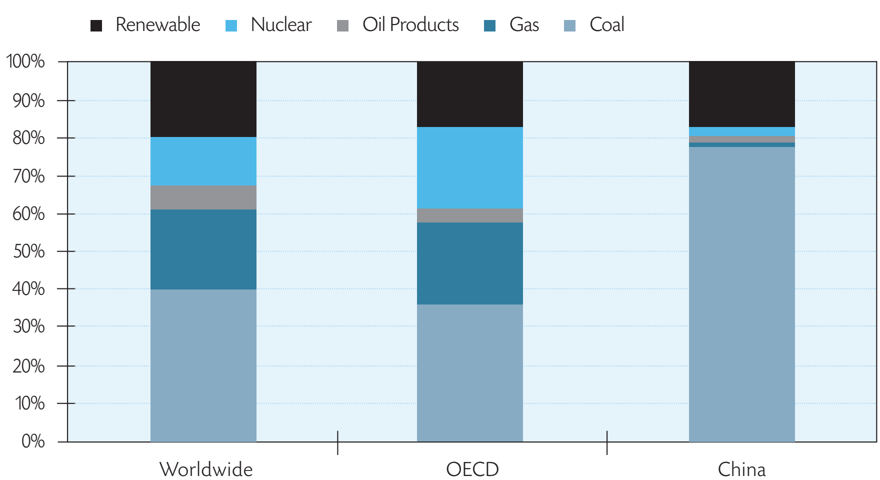
In the breakdown of energy consumption by sector, industry ranks first (50%) in China, ahead of residential and tertiary buildings (28%) and transportation (10%). In OECD countries, buildings (33%) are closely followed by transportation (32%).

1.1.2. *Electricity production*

While electricity accounts for only approximately 20% of final energy consumption, its production requires a very large amount of primary energy due to the predominance of thermal (fossil or nuclear) power plants that consume a very large amount of primary energy. The difference between the primary energy needed to produce electricity and the resulting final energy (in the form of electricity) is mainly what explains the differences in primary and final energy consumption values.

In 2008, electricity production was 20,208 TWh (billion kWh) worldwide, 10,714 TWh in OECD countries, and 3,463 TWh in China. Figure 5 shows the structure of this production by type of source.

Figure 5 *Electricity Production by Source Worldwide, in OECD Countries, and in China, in 2008 (in %)*



Source: Enerdata.

For the three ensembles, coal is the largest source of electricity production. In China, it meets 80% of needs, with the remainder currently supplied almost exclusively by renewable sources. Coal provides only 36% in the OECD countries, but electricity production from coal in the OECD (3,700 TWh) is greater than that in China (2,700 TWh). Worldwide, one can see that nuclear power (13.5%) clearly contributes less than renewable energies (19.1%).

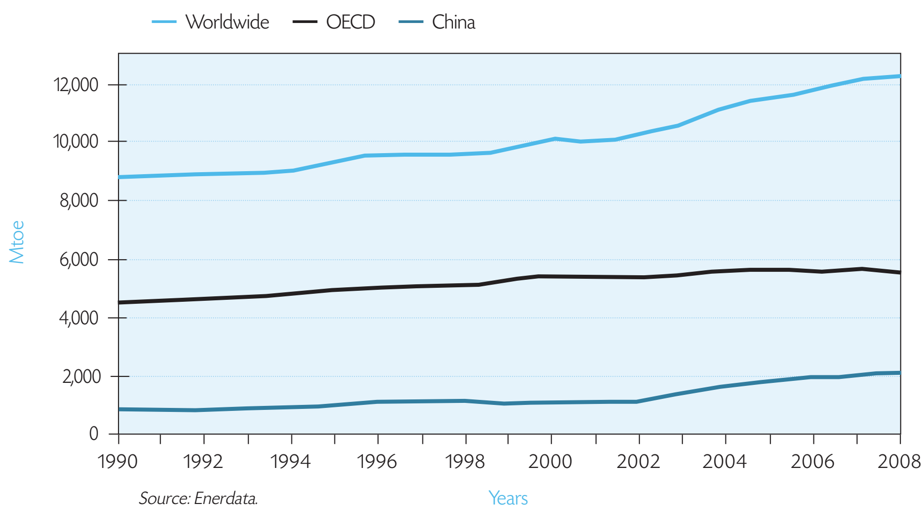
1.1.3. *Primary energy consumption*

Total and *per capita* energy consumption

Figure 6 shows the changes in primary energy consumption for the three large ensembles. While energy consumption in OECD countries was more or less stable during the 2000-2010 decade, China's energy consumption rose steadily, as did global consumption.

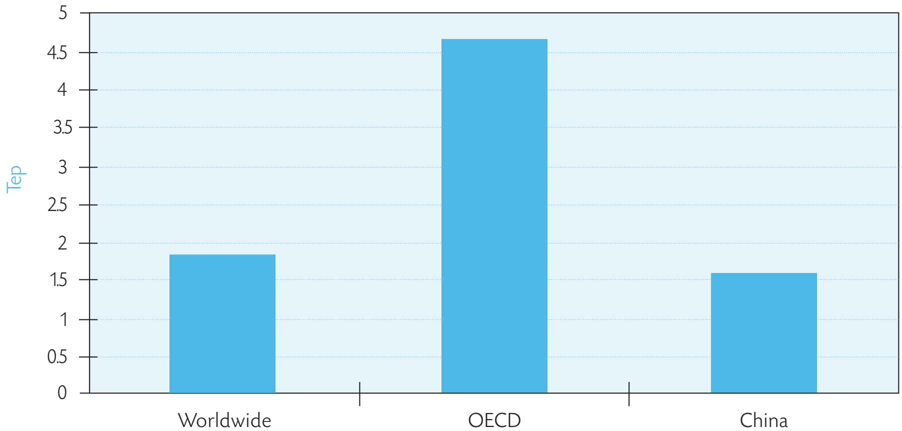
In terms of *per capita* consumption (see Figure 7), the differences between China and the OECD countries noted in the comparison of final energy consumption are, once again, highlighted.

Figure 6 *Evolution of Primary Energy Consumption Worldwide, in OECD Countries, and in China, from 1990 to 2008 (in Mtoe)*



Source: Enerdata.

Figure 7 *Per Capita Primary Energy Consumption Worldwide, in OECD Countries, and in China, in 2008 (in toe)*



Source: Enerdata.

Structure of primary energy consumption by source

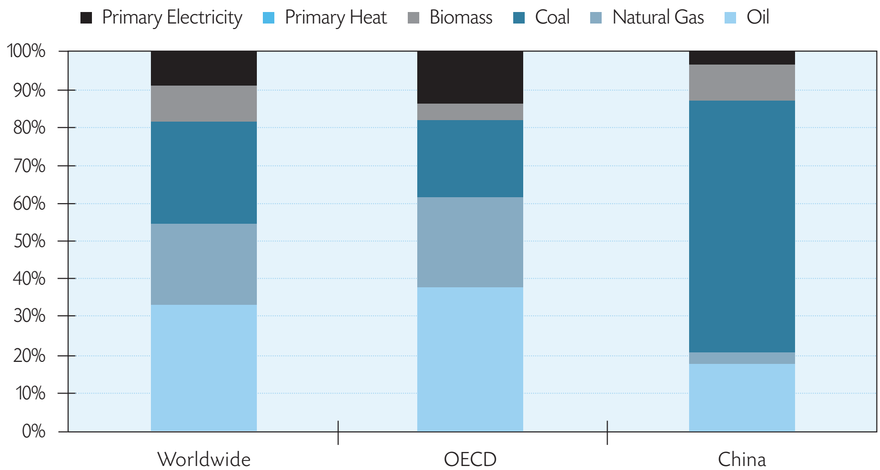
Table 1 *Primary Energy Consumption by Source, in 2008 (in %)*

%	Oil	Natural Gas	Coal	Biomass	Primary Heat	Primary Electricity
Worldwide	33.3	21.1	26.9	9.8	0.2	8.6
OECD	38.4	23.1	20.7	4.2	0.2	13.5
China	18.1	3.1	65.8	9.5	0.3	3.3

Source: Enerdata.

In the OECD countries, and worldwide, oil is the largest source of primary energy. In China, however, coal is by far the largest source of primary energy at 66%.

Figure 8 *Primary Energy Consumption by Source Worldwide, in OECD Countries, and in China, in 2008 (in %)*

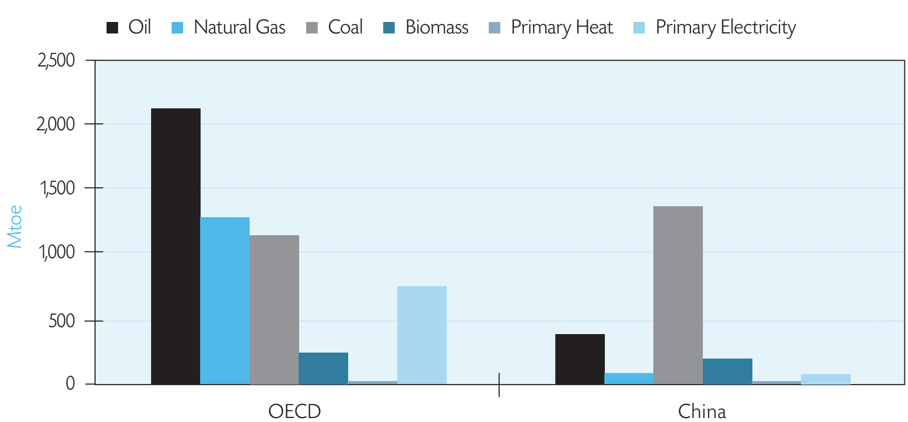


Source: Enerdata.

China and the OECD

With a population 10% smaller than that of China, OECD countries as a whole consume six times more oil than China, twenty times more natural gas, eleven times more primary electricity, and only 20% less coal and 20% more biomass (see Figure 9).

Figure 9 *Primary Energy Consumption in OECD Countries and in China, in 2008 (in Mtoe)*



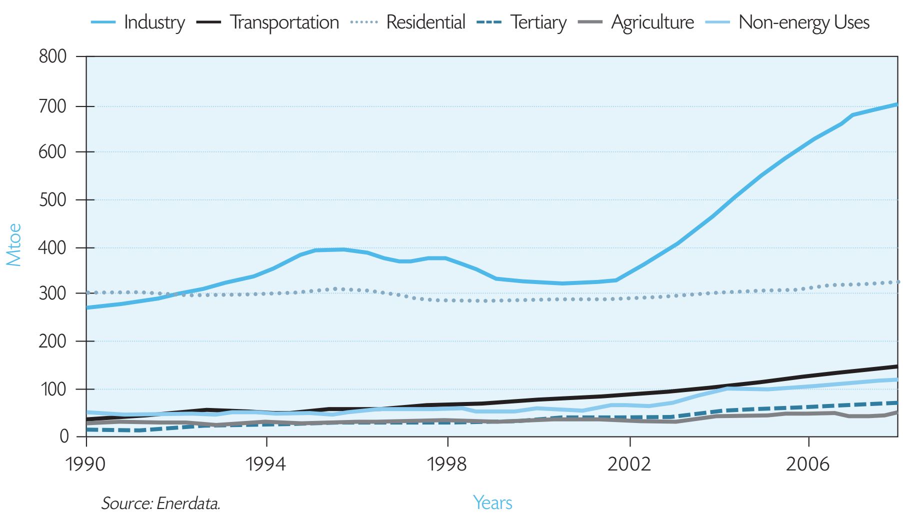
Source: Enerdata.

1.2. Energy consumption in buildings in China

1.2.1. *Final energy consumption by sector*

Figure 10 illustrates the sharp rise in consumption in the industrial sector since the start of the 2000s due to a boom in infrastructures and building construction and high growth in exports.

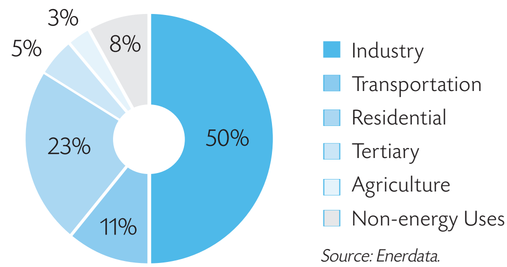
Figure 10 *Final Energy Consumption by Sector in China, from 1990 to 2008 (in Mtoe)*



Source: Enerdata.

In 2008, the industrial sector accounted for half of final energy consumption, ahead of the (residential and tertiary) building sector (28%) and transport (11%) (see Figure 11).

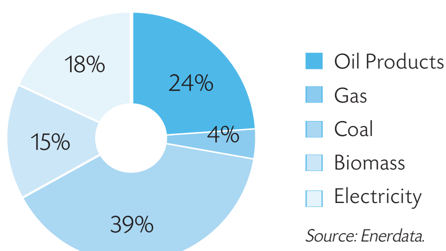
Figure 11 *Structure of Final Energy Consumption by Sector in China, in 2008*



Source: Enerdata.

1.2.2. *Structure of final energy consumption by product*

Figure 12 *Structure of Final Energy Consumption by Product in China, in 2008*

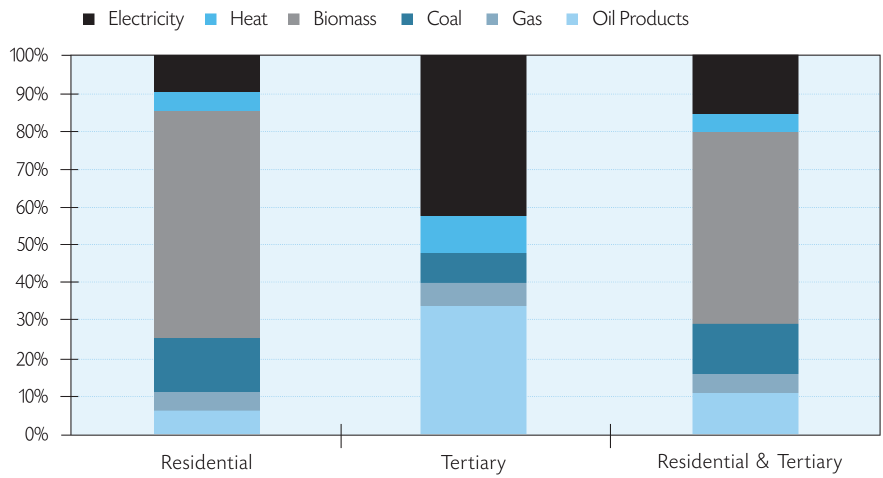


Source: Enerdata.

Directly consumed coal still accounts for a dominant share of final energy consumption (heating, notably through heat networks). For its part, gas consumption is low, while biomass accounts for a large share.

1.2.3. *Structure of energy consumption in buildings by product*

Figure 13 *Structure of Consumption in Buildings by Product in China, in 2008*



Source: Enerdata.

The structure of energy consumption by product in the building sector confirms what we saw previously: the large share of biomass (by far the largest product in the residential sector) is related to the fact that it is the heating source in rural areas (542 million inhabitants in 2006, according to the OECD). The same structure is not, however, seen in urban consumption: the tertiary sector, which is urban, has a consumption structure similar to that of western countries, dominated by electricity and oil products; but gas consumption (high in OECD countries) is currently very low in China.

1.2.4. *From primary energy to final electricity*

Total electricity production for domestic consumption needs in China was 3,452 TWh in 2008. Taking into account self-consumption and losses, total consumption was 2,972 TWh, of which 146 TWh was consumed by the energy sector, and 2,826 TWh in final consumption. This means that 1 kWh consumed corresponds to 1.16 kWh produced.

What is more, in 2008, the quantity of primary energy (mainly coal) consumed to produce electricity was 811 Mtoe, for a production of 3,452 TWh or 297 Mtoe. The electricity production system's efficiency – the ratio of the quantity of electricity produced to the quantity of primary energy needed to produce it – was therefore 0.366 (or 36.6%).

The electric system's efficiency – that is to say the ratio to the quantity of electricity consumed "at the end of the chain" (either in final consumption or in energy sector consumption) – was therefore 0.366:1.16 = 0.316.

This ratio is interesting when converting final electricity consumption (in buildings, for instance) into primary energy.

1.3. CO_2 emissions from energy consumption

1.3.1. *International comparisons*

Table 2 shows the total *per capita* emissions of the main emitting countries (including the EU, taken as a whole). The CO_2 emissions considered here are those caused by the combustion of fossil fuels.

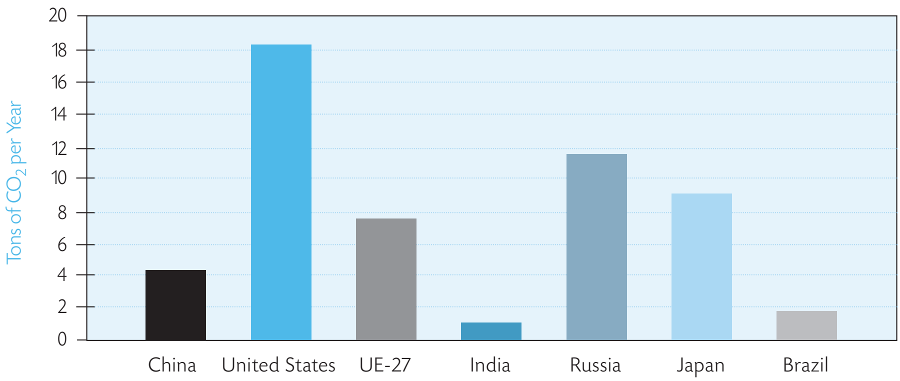
Table 2 *Total and Per Capita CO_2 Emissions in the Main Countries, in 2008*

2008	CO_2 Emissions in Mt (million tons)	Population in millions	*Per Capita* CO_2 Emissions in t (tons)
China	5,836	1,328	4.40
United States	5,578	305	18.27
UE*-27	3,823	496	7.71
India	1,380	1,141	1.21
Russia	1,637	141	11.60
Japan	1,173	128	9.18
Brazil	356	195	1.83

** EU: European Union (27 countries).*
Source: Enerdata.

One can see that, while China was the largest emitter in 2008, its *per capita* emissions were still four times less than those of the United States, three times less than those of Russia, and roughly half those of Japan and the EU. Brazil and India were far behind.

Figure 14 *Annual Per Capita CO_2 Emissions in the Main Countries, in 2008 (in toe)*



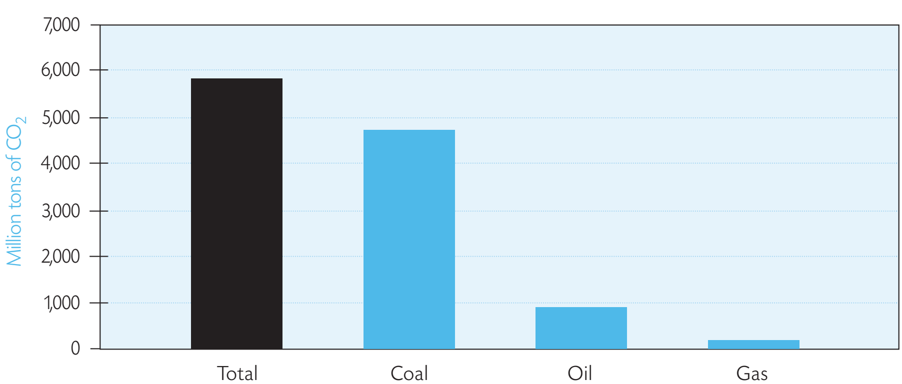
Source: Enerdata.

1.3.2. *Energy-related CO_2 emissions in China*

CO_2 emissions by source

Out of a total of 5,836 Mt of CO_2 in 2008, unsurprisingly, 82% of CO_2 emissions come from burning coal.

Figure 15 *CO_2 Emissions (combustion) by Source in China, in 2008 (in Mtoe)*



Source: Enerdata.

CO_2 emissions by sector

When indicating emissions by sector, it is usual to consider the energy sector as a specific sector. All of the emissions in this sector are therefore counted. However, energy production is not a goal in itself. This energy fuels consumption sectors, and it is more interesting to count, for each sector of final use, a share of direct emissions (coal heating, automobile travel, etc.) and indirect emissions (notably to produce electricity). Table 3 and Figure 16 illustrate this.

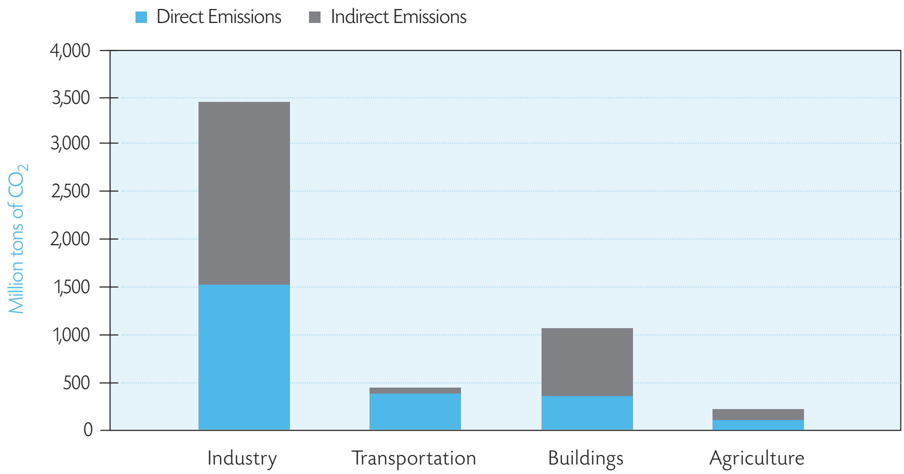
Table 3 *Direct and Indirect CO_2 Emissions by Sector in China, in 2008 (in Mt)*

CO_2 Emissions (Mt)	Industry	Transport	Buildings	Agriculture	Total
Direct	1,540	426	378	123	2,467
Indirect	1,913	27	701	100	2,741
Total	3,453	453	1,079	223	5,208
%	66.3	8.7	20.7	4.3	100

Source: Enerdata.

It should be noted that the difference of 628 Mt between total emissions (5,836 Mt) and the sum of direct and indirect emissions in sectors (5,208 Mt) corresponds to emissions from the energy sector's own consumption (emissions from mining, refineries, and power plants).

Figure 16 CO_2 Emissions (combustion) by Major Sectors of Final Consumption in China, in 2008 (in Mt)



Source: Enerdata.

1.4. Stakes involved in energy consumption in buildings in China

1.4.1. *Energy consumption in buildings in three representative countries*

In order to evaluate the challenges of energy consumption in buildings, we are comparing this consumption in three large countries or groups of countries: China, the United States, and the European Union (the EU at 27 countries).

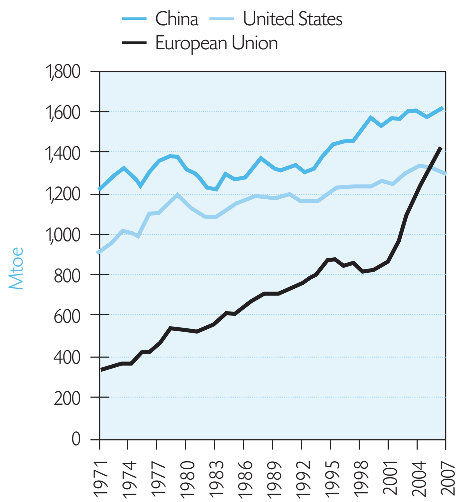
China is the largest of the emerging countries; it is undergoing strong economic growth, which is causing a rapid increase in energy consumption. The United States and the EU are two entities representative of the level of wealth of OECD countries, but with development models and lifestyles that are quite different from one another, which results in considerable differences in their respective energy situations.

Figure 17 shows that the total final energy consumption of the three countries was very similar in 2007, but growing slowly in the United States and the EU and rising rapidly in China.

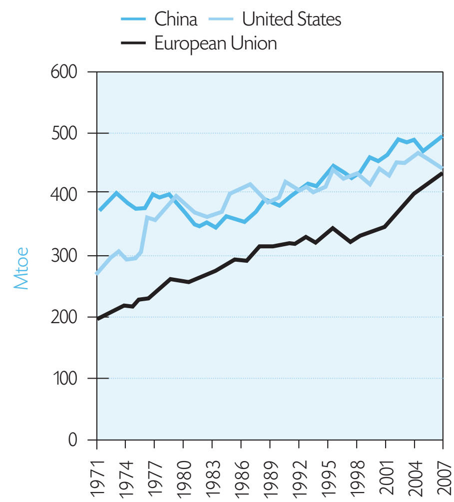
Almost the same observation can be made of final energy consumption in the building sector (residential and tertiary combined), with slower growth than previously in China's case (see Figure 18).

Figures 17 and 18 *Final Energy Consumption Total and in Residential and Tertiary Sectors, in China, the United States and the EU, from 1971 to 2007 (in Mtoe)*

17. Total Consumption



18. Residential and Tertiary Sector Consumption



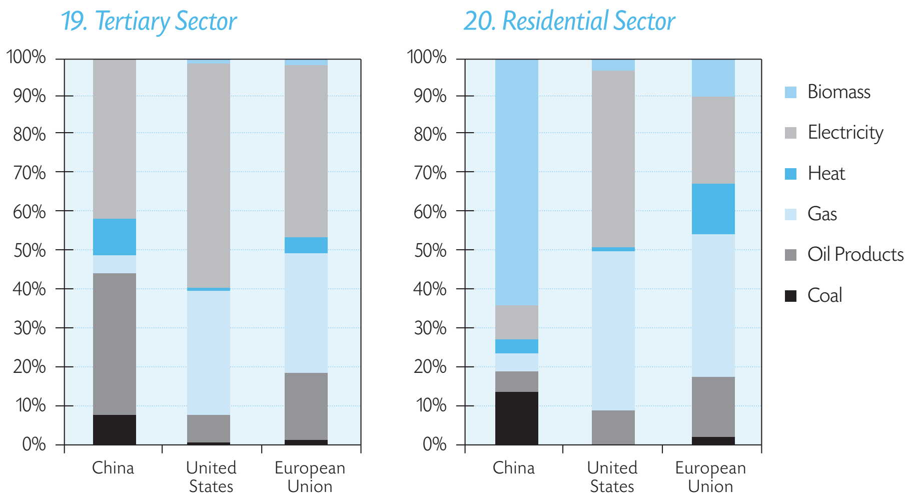
Source: Enerdata.

Considerable differences can, however, be seen in the structure of final energy consumption in buildings in each of the three major consumers, as shown in Figures 19 and 20.

The largest difference can be seen in the residential sector (see Figure 20). Because of the size of the rural population in China and the fact that it uses mostly firewood for heating and cooking, biomass accounts for a predominant share of consumption, whereas the United States and the EU use mainly electricity and fossil fuels (especially gas).

Between China and the two other countries, the structure is more similar in the tertiary sector (see Figure 19), developed almost exclusively in urban areas and above all in large cities: use of fossil fuels (preponderance of coal in China, and of gas in the United States and in Europe) and electricity.

Figures 19 and 20 *Structure of Final Energy Consumption in the Residential and Tertiary Sectors in China, the United States and the EU, in 2007 (in %)*



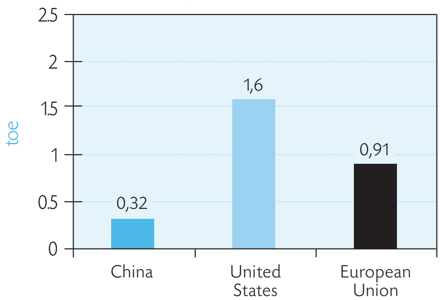
Source: Enerdata.

1.4.2. *Per capita consumption*

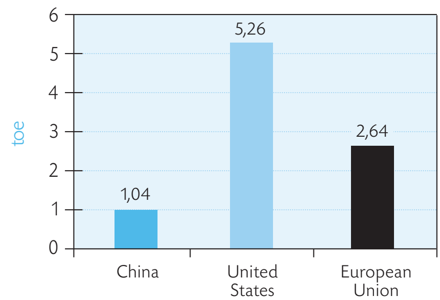
Comparing overall consumption provides useful information and establishes orders of magnitude. It is however necessary to take into account one major factor differentiating China, the United States and the European Union (EU): the population, that is to say the number of consumers (in 2007, there were 1,321 million people in China, 302 million in the United States, and 494 million in the EU, according to OECD data). Thus, total final energy consumption and final energy consumption in the residential and tertiary sectors are very different, as can be seen in Figures 21 and 22.

Figures 21 and 22 *Final Energy Consumption Total and in Residential and Tertiary Sectors, in China, the United States and the EU, in 2007 (in toe)*

21. Residential and Tertiary Sector Consumption



22. Total Consumption



Source: Enerdata.

1.4.3. *Estimated Energy Efficiency Challenges in Buildings in China*

The energy consumption situation in China varies widely between "energy guzzling" ultramodern urban centres and rural regions where the energy supply is very low and still mostly provided through traditional sources.

China's economic growth will progressively lead to increased comfort levels and, generally speaking, energy services for a growing proportion of the population, accompanied by increasing urbanization. We should therefore see a dual movement: on the one hand, the consumption gap between urban and rural areas should narrow and average *per capita* energy consumption should increase (because a larger number of people will obtain access to energy services and because of the increased energy demand associated with each energy service), while on the other hand we should see increasing use of modern energy products replacing traditional energies, with a growing share attributed to renewable energy.

This development will happen taking into account the geographic context and climate in China and the specificities of the ways of life of the populations concerned, as well as territorial development, urban planning and, more generally, housing and construction policy and the more or less extensive consideration of energy efficiency techniques, economics and behaviours. It is important for policy makers to "get an idea" of the order of magnitude of the stakes behind this or that policy direction or set of behaviours.

To make such an estimate, we used the comparison of *per capita* consumption in residential and tertiary buildings presented in the previous chapter. For this, we imagined two energy consumption development scenarios for these two sectors in China:

- the first scenario assumes that *per capita* energy consumption in these sectors will converge with current consumption in the United States, or 1.60 toe per capita.
- the second scenario assumes that *per capita* energy consumption in these sectors will converge with current consumption in the EU, or 0.91 toe *per capita*.

These figures will converge at an undetermined date sometime in the next two to three decades.

With the first scenario, assuming that the population of China is constant during this period, energy consumption when convergence is reached in the residential and tertiary sector would hit 2.1 billion toe, and 1.2 billion toe with the second scenario, or a difference of 900 Mtoe in annual final energy consumption for the residential and tertiary sectors combined.

If we adopt, for each scenario, the same ratio of final energy consumption to the quantity of primary energy necessary to supply this consumption, we obtain the following values for the quantities of total primary energy in China:

- for the first scenario (convergence with the United States):
  2.1/0.48 = 4.4 billion toe;
- for the second scenario (convergence with the EU): 1.2/0.60 = 2 billion toe.

The gap – 2.4 billion toe in annual primary energy consumption – shows the magnitude of the stakes.

This estimate is neither a projection nor even a possibility: it is certain that China's development will follow original paths that will certainly differ from the models and ways of life in the United States and Europe. The results of the exercise do, however, provide a reasonable order of magnitude for the consequences on energy consumption of the choice or continuation of an energy-guzzling model, in particular as regards electricity uses. The present exercise, based on the notion of "catching up", must be seen as a warning for policy makers and economists. It provides valuable arguments in favour of building an energy efficient civilization.

Part Two

2. Energy efficiency retrofitting of buildings: the research program methodology

2.1. Energy efficiency in buildings

On the technical level, energy efficiency in buildings presents itself similarly in the residential sector and the tertiary sector and concerns three main items:

- the quality of building construction in terms of energy efficiency for both heating and cooling;
- sobriety in the use of energy-consuming equipment and equipment performance (using high efficiency equipment); and
- the choice of the most suitable form of energy or technique for each use (for instance, solar water heater or cogeneration).

This similarity in technical issues allows us to group the two sectors together for action programs. However, while the residential sector is relatively homogenous in uses, the tertiary sector is composed of sub-sectors with widely differing activities. It is a very heterogeneous sector, in terms of both the activities and uses it covers and how the sub-sectors are structured and organized. Intervention, promotion and incentive methods, and the approaches taken by partners are quite different because of the nature of the owners and, or contracting bodies involved.

2.1.1. *New buildings*

The main policy measure for new buildings is the elaboration and implementation of thermal regulations. For application to be real and effective, it must be accompanied by three types of activities:

- intense communication, promotion and incentives targeting sector professionals and the general public; precise evaluation of cost premiums; and the establishment of appropriate incentive measures and practical ways of accessing these incentives.

- research and development: bioclimatic architecture is a field in which Chinese researchers can contribute extensively for each climate zone, all of which require appropriate solutions. These programs should in time allow the construction of very energy efficient buildings to progressively become widespread.
- an industrial policy implemented on the national and provincial level to develop industries producing energy efficient construction materials and equipment (double-pane windows, blinds, household appliances, lighting, etc.).

2.1.2. *Existing buildings*

Energy consumption in existing buildings should increase because of aspirations to greater comfort. This increase will "waste energy" (for heating and air conditioning) because of the poor thermal condition of most existing buildings. It is therefore necessary to implement an energy efficiency retrofitting program for existing housing and tertiary buildings. However, at the current market prices, the payback time for this operation is not very attractive for building owners, even if the interest for society is clear. Therefore, an incentive system for thermal retrofitting investments needs to be set up in the form of subsidies or soft loans. Consulting the partners concerned should make it possible to choose the best solution. Eventually making "thermal renovation" mandatory for all existing buildings containing heating and/or air conditioning systems must be envisaged.

2.1.3. *Electricity savings in housing*

In the residential sector, the potential of energy efficiency in electricity consumption concerns four uses: lighting, household appliances (primarily refrigerators and freezers), air conditioning, and stand-by modes (on household appliances and audiovisual equipment).[5]

There are two main ways to act on the energy consumption for these uses, for the same or better service: modify consumers' behaviours, and improve the energy efficiency of the appliances used through regulatory measures and financial incentives:

- *consumer behaviour* can be modified through information and awareness-raising campaigns targeting habits (*i.e.* turning off lights) and purchases (*i.e.* buying energy-efficient appliances), and thinking about the scope and nature of real needs (*e.g.* even if one can afford it, does a family really need to own

[5] One must also take into account the production of domestic hot water by solar water heaters.

several television sets?). Influencing behaviour is primarily a question of information and awareness raising, not only on possible choices and the financial interest of these choices (addressing the consumer in this case) but also on the consequences of these choices (addressing the citizen in this case). The scope of the awareness raising will be considerably improved if regulatory measures and financial incentive are implemented in parallel.

- *regulatory measures:* certification and labelling. The most effective measure is to set maximum consumption standards for given appliances (for instance, standards on refrigerator consumption and volume), and establish labels [6] on relative appliance performance. This raises two issues: control of proper application of regulations and, beyond communication, incentives that will encourage, based on regulations, the best possible results when it comes to rational energy use. The certification and labelling process should also be applied to other types of appliances: individual air conditioners, hot water heaters, lamps and lighting fixtures, washing machines, clothes dryers and combination (washer-dryer) machines, dishwashers, ovens, irons, and audio-visual equipment.

There is obviously a link between the outcome of behaviour modification and technical improvements. The latter can sometimes make up for deficiencies in the former, but it would be an illusion to think that energy efficiency is essentially a technical matter. Policy decisions on development and planning, as well as citizens' attitudes about their consumption of goods and services are both decisive.

2.1.4. *Promotion and incentives in the tertiary sector*

In the tertiary sector, the program targets the following:

- existing local government building stock and public lighting;
- public tertiary buildings: administrative offices, hospitals, teaching establishments; and
- private tertiary buildings: office buildings, shops, hotels.

While the technical solutions for tertiary buildings are similar to those for residential buildings, the communication methods and incentives need to be fine-tuned. Indeed, they will be more similar to the efforts in the industrial sector than to solutions and measures applicable in the residential sector.

[6] Once the labeling process is fully established, measures banning less efficient categories can be envisaged. The best way to proceed is to eliminate the latter and "slide" the scale upwards to include higher performing categories.

Local Governments

Local team and the inter-city energy advisers

For public lighting and building stock owned by the local government, it is important that the municipal technical services form a local team that is either part of the municipality or separate from it. For small cities, especially in rural areas, the "inter-city energy adviser" is a very interesting and relatively inexpensive formula that has been implemented in several regions of France, and this experience could be utilized.

The question of rural cities and villages must be examined in a comprehensive manner, both in regard to rational energy use (buildings, agricultural equipment) and also in regard to the development of local renewable energies such as fuelwood in certain regions and solar energy throughout the country (bioclimatic architecture, solar heating systems, photovoltaic solar energy in isolated sites).

Companies and establishments in the tertiary sector

Elaboration and implementation of action programs by sub-sector

Each tertiary sub-sector has specific characteristics, so it is necessary to promote energy efficiency in ways that have been tailored to each sub-sector's specificities.

In consultation with a given sub-sector, one can envisage two types of projects: establishment-specific projects or horizontal projects targeting a set of establishments.

An energy audit of a tertiary building can provide an opportunity to reinforce the capabilities of a tertiary building's technical team. Staff training sessions can be organized at this time, for instance.

When a sub-sector or set of establishments within a sub-sector is sufficiently uniform, it is easy to identify rational energy use operations that can be applied to all establishments in the set. This is especially true for energy efficient lighting and cooling equipment, as well as certain types of audiovisual and computer equipment (*e.g.* television sets, computers). Bulk equipment purchases or even grouped procurement operations (*i.e.* calls for tender) in which candidates must meet minimal energy performance criteria on the equipment supplied can be envisaged to lower costs. These projects must be able to receive financial aid for investments.

Investment incentives and support

The key to being able to go from intent to action following an energy audit or discussions with sector representatives lies mainly in the financing capacity of the establishment (and administrative rules in the case of public tertiary buildings).

The intervention of energy service companies (ESCOs), that invest in place of the energy consumer, is particularly interesting in the tertiary sector because it generally has neither the technical skill (while industry generally does) nor the investment capacity to invest in rational energy use (or energy substitution), even when it is very profitable. Operations of this type would be quite interesting in hospitals that could recover the initial investment through the savings in the operating budget from the energy savings generated by the investment.

2.2. Components and framework for an energy efficiency building retrofitting program

Energy efficiency retrofitting of buildings mainly address energy consumption for thermal comfort and, as a result, heating or cooling the inside of the building. It focuses in priority on the quality of the building envelope (walls and openings), architectural design, and orientation (solar gain management). Usually, in accordance with thermal building code conventions, energy efficiency retrofitting addresses five uses: heating, cooling, ventilation, hot water supply, and lighting. Actually, energy consumption in a building also covers the energy used by appliances and equipment devoted to other uses, and in particular household or professional electric appliances. It will therefore be important – out of concern for energy efficiency which must focus on total energy consumption in the building – to accompany thermal renovation programs with policies and measures addressing the energy efficiency of these appliances.

The thermal renovation of a building consists of three types of components:

- technical aspects (design, materials, equipment, etc.);
- economic aspects (cost, benefit, and social, energy and environmental impacts); and
- financial aspects (incentives and financial mechanisms for the investments).

Conducting a large-scale retrofitting program on existing buildings obviously implies implementing these components, but its success depends upon the setting up of an organizational and institutional framework to mobilize partners, taking into account the respective responsibilities of the State and the market.

2.2.1. *Technical tools and interventions*

Technical interventions deal with insulating walls, upgrading openings, the heating system, air conditioning, the hot water supply system, ventilation and regulation. Concretely, they involve different types of actions:

- insulating roofs and outside walls: technical choices (exterior insulation, interior insulation, insulation included in structural materials);
- replacing doors and windows, installing blinds or shutters;
- upgrading or replacing the heating system (boiler, energy product used);
- upgrading or replacing the ventilation system;
- upgrading or replacing the air conditioning system (air conditioner, energy vector);
- upgrading or replacing the hot water supply system (*e.g.* installing solar water heaters); and
- installing or optimizing the heating, ventilation and air conditioning regulation system.

These technical improvements must imperatively be accompanied by very strictly organized maintenance, without which the gains acquired thanks to the renovations risk deteriorating rapidly due to a lack of maintenance, supervision and adjustment of the equipment and systems installed. Particular attention should be paid to the behaviour of users occupying the building: setting a comfortable temperature (in winter and summer), monitoring lighting, putting equipment in stand-by mode or turning it off, etc.

2.2.2. *Project and program savings and impact assessment*

The cost of energy efficiency actions and measures varies greatly, from almost nothing or very little (user behaviours, adjusting the comfort temperature, quality of maintenance, installing sun shades on windows, etc.) to very expensive for extensive technical modifications (insulating roofs and walls, replacing furnaces, etc.). Even when the action is inexpensive, actions dealing with behaviours and maintenance require information, training and expertise efforts: the need for qualified human resources (and therefore the corresponding funds) must be taken into account when designing a retrofitting program.

Most of the significant actions when to exploit the energy saving potential require investments. The first evaluation of their economic interest is done by comparing the investment cost to the energy spending avoided each year following the renovation.

This evaluation is conducted at consumer level (usually the building owner), based on the price of the energy product saved. This is how the "investment payback time" is calculated, which allows one to evaluate the interest, for the consumer, of going ahead with the operation. Let us note that this is not limited to energy savings: the thermal renovation of a building is generally part of a more extensive renovation that increases the value of the building. In "developed" countries, this increase is furthermore the main incentive to renovate, ahead of the payback time based on the simple calculation of cost savings because the payback time is generally long due to the cost of labour.

Beyond the direct economic interest for consumers, it is crucial to assess the impact of these actions in a more comprehensive way and looking at different aspects:

- the overall energy savings associated with a renovation program;
- gains for society (in the city, province or country) in terms of savings on energy imports and the investment in additional energy production (notably investments to build power plants);
- social gains: improved comfort and quality of life or working conditions, activity generation, job creation; and,
- environmental gains: reducing local pollution (from certain heating systems) and greenhouse gas emissions.

These impact calculations show that, although each individual renovation represents only limited energy savings, multiplying these renovations by the number of buildings likely to be renovated adds up to considerable savings.

Assessing overall impacts is fundamental to provide economic and political decision makers with numbers so that they can appreciate the importance of a large-scale building retrofitting program when it comes to economic growth, social benefits and environmental improvements. It is an indispensable element in decision making.

2.2.3. *Incentives and financial mechanisms*

We know from experience that, even if a thermal retrofit of a building is economically interesting, it will not be done "spontaneously" for a number of reasons that can be grouped roughly into two categories:

- a lack of information and promotion and, correlatively, the weakness of professional actors able to carry out these projects in optimal technical and economic conditions; and

- difficulties, by the contracting authority, mobilizing the funds needed to finance the project.

It is of strategic importance to provide solutions to these two problems if one wants to develop large-scale retrofitting programs. This means that incentive systems and/or financial mechanisms facilitating the initial investment (based on economic assessment and the expected overall impacts) need to be set up and, simultaneously, a conducive framework for these investments needs to be created in terms of regulations, expertise, technical capacities, easy access to energy efficient techniques and equipment, etc.

2.2.4. *New actors for a transverse activity: consultation and partnership*

Energy efficiency retrofitting of buildings is an undertaking that brings together all the characteristics, difficulties and advantages of energy efficiency actions on the demand side. Indeed, compared to actions targeting the "energy supply" (generally implemented by large energy operators with powerful technical and financial means), energy efficiency in existing buildings addresses a multitude of consumers and agents or partners: administrations, designers (architects, consultants), occupants, enterprises in diverse fields (materials, construction, heating, air conditioning, etc.), equipment suppliers, banks and other financial organizations.

In China's new energy policy, which gives equal importance to the "demand side" and the "supply side", new actors emerge, generally little familiar with energy issues but having a crucial role to play throughout the chain of operations. It is therefore vital that programs be designed in conjunction with decision makers in major sectors of activity: governmental and administrative leaders, enterprises in the industrial and tertiary sectors, building contractors and real estate promoters, importers and equipment vendors, local governments and consumers' associations, public and private financial organizations, etc.

Consultation and partnership are therefore indispensable to program elaboration, determining the resources needed for implementation, and program implementation itself. The role and responsibility of public authorities is to create the system and means that will allow energy efficiency to be an integral part of all of these actors' and economic agents' activities.

2.2.5. *The Public authorities and the market*

The market cannot on its own take into consideration either long-term concerns (climate change, dwindling resources) or all the environmental and social externalities related to energy consumption and production that exist outside the market. Only a long-term vision of the goal of sustainable development under the responsibility of the State or local governments allows one to guide the energy strategies of actors in the market toward the general interests of the national and international community. In this regard, let us recall that international commitments in the fight against climate change, for instance, are the States' responsibility.

In addition, and this is particularly true in emerging and developing countries, future energy consumption will be based very directly on infrastructure development and the choices made in economic sectors that are not directly related to energy (construction, transportation, industry). The decisions guiding these sectors and the corresponding investments will therefore be decisive in controlling long-term energy consumption. Yet, experience acquired since the 1980s shows that the behaviour changes and investment decisions of a very large number of actors – as well as national decisions on large infrastructures (transportation, housing) – do not spontaneously, under the influence of the market, move toward greater efficiency, even when energy prices correctly reflect costs. This is why public intervention is crucial to ensuring the long-term interests of society, defending consumers' rights, and ensuring that the environment is protected and improved.

The institutional issue – that is to say, how public authorities, both national and provincial, will play this role promoting, organizing and coordinating the network of partners – is absolutely vital to the success of large-scale programs.

2.3. Main methodologies utilized in the research program: a comprehensive, partnership-based approach

The joint research program undertaken under the dual responsibility of Hubei Province and the AFD was guided by the awareness that the interests of the two parties converge and by the need for a comprehensive approach able to overcome the various constraints discussed above. Hubei Province, located in south-eastern China, has a population of approximately 60 million people; its capital is Wuhan, a city with a population of nearly 9 million and one of the 10 largest cities in the country. The research program focused exclusively on buildings in this city, but its methodology can be applied to the entire province and beyond.

The research program's principles and organization were established jointly by the teams of administrative leaders and experts, formed under the authority of each of the partners – the Hubei Province Construction Department and the AFD Research Department. The combination of a team of experts, managers and staff from the provincial administration, and academic teams made it possible to elaborate an applied research project with an awareness of global stakes and a simultaneous requirement of quality in concrete achievements.

2.3.1. *A common interest*

Whether in China, California, France, India, Indonesia, South Africa or anywhere in the world, in wealthy or poor countries, as well as energy exporter or importer countries, everyone has an interest in increasing the energy efficiency of one's economy. Also, everyone has an obligation to ensure economic and social development, energy security, and local and global environmental protection or improvement simultaneously and on the local, provincial and national levels. These obligations come with strong constraints – resources, costs, people's needs – and converge toward the absolute need for energy efficiency in all sectors: transportation, industry, and above all buildings, which are becoming the leading sector for energy consumption (in particular electricity). Energy efficiency is therefore a priority response to this convergence of development obligations and energy and environmental constraints. This convergence of interests is therefore a powerful factor in international cooperation, and this can be seen in the quality of joint work produced by the teams in this research program. Finally, one should remember that this convergence appears at different levels: national, provincial and municipal governments, individual consumers, enterprises, universities, financial bodies, etc.

2.3.2. *Complementarity and coordination of responsibilities and means of action*

Concerning the reseach methodology, given the very large number of elements involved, the temptation was great – as is generally the case – to tackle each question separately in sequence, and to assemble the results obtained at the end of the sequence. For instance, engineers tackle technical questions, economists evaluate costs, then institutional, organizational and finally financial questions are addressed.

Complementarity was the leading principle in the progression of the research program. This means that the various expertise groups – rather than attempting to follow the sequence blindly – worked simultaneously, and their progress and results at each stage interacted so that the points of view and choices of the various parties were heard and taken into consideration at each stage. In this way, we attempted to avoid the classic schema in which *(i)* the technicians design "the best solution" on their own; *(ii)* then interdisciplinary dialogue reveals that the funding to apply said solution is missing; and *(iii)* the financial criteria or a policy decision force a revision of the choices made.

Energy efficiency projects can be technically possible and economically interesting, meet energy and environmental constraints, and more. In other words, they can appeal to everyone. Yet, they will not be implemented if the organizational and financial conditions are not met. This is a complicated process in which wealth in energy resources is replaced by intelligence, imagination, organization, technical and financial innovation. These elements make up the wealth and superiority of energy efficiency as a favoured sustainable development instrument. To successfully conduct this process, inter-disciplinary complementarity and interaction are indispensable.

It is clear: energy efficiency is a field in which means of action are complementary and in which one must "run with" a complete range of instruments. The success of a given program will not depend on one "single solution" but on a coherent and balanced ensemble made up of political will, laws and regulations, information and training, organized partnership, financial incentives, and the implementation of specific financial mechanisms. One must know how to "grease the wheels" or, in other words, organize, instigate, and run complementarity in a harmonious fashion. This need is the one most often forgotten, as if all these actions happen spontaneously. This is not the case: someone must do them. Indeed, it is not enough to say that everything comes from the government and, hence, everyone must obey. That does not work. At the same time, we must not think that everything comes from the market and that the market will fix everything through some mysterious operation. This often leads to disastrous situations.

The key is indeed articulating different activities and disciplines, their interactions, and different forms of authority and decision-making: policy (government and local and regional authorities), industry (construction, material and equipment companies), research and expertise (universities, consultants, energy service companies), and finance (public budget, banks, investment funds, ESCOs, etc.). For each instance, for each project or program, the combination and harmonization of each party's skills is what will ensure the quality of the work. Coordinating the various responsibilities (and ensuring that each responsibility is correctly fulfilled) is the key to success.

2.3.3. *Diversity in situations and responses*

Energy efficiency program responses will differ depending on the type of building, the nature of the owner and the activities that take place in the building. The very same building will have different energy needs and energy use modes depending on whether it contains offices, a hospital, a department store, or housing units. While the technical responses can be the same (in varying proportions), the financial responses will almost always be specific. In one case, for a prestigious or emblematic building, the public budget will cover the necessary financing to make the building an example of energy efficiency (a "showpiece") or a pilot operation. In most cases, however, the best solution will need to be found among various possibilities: subsidized loan, intervention by an energy service company, etc. Addressing these questions requires one to have an open mind and not simply say "here's the solution": there are three or four possible solutions.

Diversity can also be seen in where the authority lies and who makes the decisions. The issue underlying all the discussions on this topic is the balance between the government and the market, and the division of the various tasks and responsibilities. While the government is clearly responsible for laws and regulations, it cannot limit itself to passing and enforcing laws. Indeed, it must also inform and facilitate compliance: establishment of a specific framework, creation of thermal regulations and regulations on the energy efficiency of equipment and appliances, formulation of information, training and incentive measures so that architects, consultancy firms and companies can build, renovate and equip energy efficient buildings. Except over its own property, the government does not have direct responsibility for "doing things" but it is responsible for creating the conditions that allow "things to be done." In a symmetrical and complementary manner, market actors must for their part get organized and acquire skills to be able to respond to the collective interest. One cannot say, "I'm in the private sector, I'll do what I want," and then ask for subsidies or favourable legislation the next day. This diversity must be understood so it can be placed at the service of society.

2.3.4. *An interactive, iterative and ongoing method*

The research program's methods were not limited to conducting, once and for all, a set of tasks happening in specific phases and leading, at the end of the process, to one or more outcomes seen as definitive. The method was interactive, iterative and ongoing:

- *interactive* because the results of this or that phase or task would cause adjustments to be made to the other phases or tasks, and because, in most of the paths from one task to another, the reverse path needed to be taken into account (for example, the influence of energy impact calculations on the choice of buildings for the continuation or deepening of the investigation).
- *iterative* because, in practice, the process of elaborating proposals regarding the resources to implement would begin again when all the issues had been studied. The assessment of impacts and proposed financial mechanisms, as well as the available means, would partially influence the technical choices and magnitude of the retrofitting operations, with each level of retrofitting bringing greater energy efficiency but also greater costs that could not always be covered. In addition, the work in partnership with the various actors made it possible to better understand consumers' expectations and actors' roles, consequently bringing about more precise and better targeted formulas in the action planning.
- *ongoing* because the steering and animation work during the research and program elaboration phase would need to be continued during the implementation phases, not only to ensure the work was done properly but also to learn lessons that would make it possible to modify or improve the methods and instruments for energy efficiency retrofitting in buildings.

2.4. Research program organization

Translating the methodological principles described above into organizational terms for the research program led us to structure the teams' work in an original and innovative manner (compared to traditional practices in this type of program).

Indeed, research in this field is usually organized "sequentially" as a logical series of sub-programs: study of technical solutions (up to and including implementation of pilot projects), statistical studies or surveys to obtain knowledge on energy consumption, elaboration or use of energy consumption simulations, economic calculations, and evaluation of the challenges. Once these stages have been completed – which takes a certain amount of time – the policy and regulatory framework of the sector, the search for partnerships, and the crucial issues of investments and financial means are eventually addressed.

The way the work was organized in this program was, on the contrary, based on work "in parallel" that, from the start, made it possible to become aware of the importance of institutional and financial issues and attempt to address them in conjunction with the development of other components. This type of organization also made it possible to save time, make technicians and even economists aware of the importance of these issues from the start of the research, and guide technical and economic choices depending on of institutional and financial realities and constraints.

2.4.1. *Structure of the research team*

The research teams were organized in three working groups (WGs) – A, B and C – with each group in charge of one major component of the research in energy efficiency retrofitting of buildings:

- WG A: technical and economic analysis;
- WG B: institutional and organizational issues; and
- WG C: financing investments.

The work of each working group was sub-divided into various activities (A1, A2, B1, B2, C1, C2, etc.). Table 4 gives the various activities assigned to each working group.

Table 4 Breakdown of Activities by Working Group (WG)

WG A Technical and Economic Analysis	WG B Institutional and Organizational Issues	WG C Financing Investments
A1 Typology of existing buildings.	B1 Organization of the building sector and energy management in buildings.	C1 Dialogue and exchange with financial institutions.
A2 Energy consumption in buildings.	B2 Energy supply system and price of energy.	C2 Analysis of the building construction and renovation market.
A3 Energy consumption calculation tools.	B3 Institutional framework for energy efficiency and building retrofitting.	C3 Analysis of financing practices in the building sector.
A4 Energy efficiency actions and measurements in buildings.	B4 Legislation, regulations and fiscal system related to buildings and energy efficiency.	C4 Experience in energy efficiency in buildings in China, abroad, and international cooperation.
A5 Impacts of programs targeting energy efficiency retrofitting in buildings.		C5 New financial mechanisms.

Source: the authors.

The various tasks and how they were executed will be discussed in detail in the following chapters.

2.4.2. *The formation of working groups*

The Chinese part, run by the Hubei Province Construction Department, set up a team of approximately thirty people, composed of experts from the committee, engineers from the Wuhan City Energy Efficiency Bureau, the Municipal Bureau of Land Resources and Housing Management, researchers from Huazhong University of Science and Technology (school of public administration and school of architecture and urban planning), and economists and financiers from Zhaoshang Bank and Mingsheng Bank.

Table 5 *Sample Tasks in the Activities of the Three Working Groups (WGs)*

A1 Typology of existing buildings	**B3 Institutional framework for energy efficiency and building retrofitting**	**C3 New financial mechanisms**
A11 Building categories and basic characteristics.	B31 How building renovation actors are organized.	C51 Existing financial sources and mechanisms Identification of necessary improvements or creations.
A12 Energy consumption in the sub-categories of buildings in the tertiary sector.	B32 Organization and means to promote energy efficiency.	C52 Interest and feasibility of a fund for energy efficiency retrofitting in buildings.
A13 Economic and managerial data for selected buildings.	B33 Proposals for building retrofitting sector organization and support.	C53 Study of public-private partnership conditions.
A14 Collection of all the data needed for an energy efficiency action plan in these buildings.	B34 Proposals to improve energy efficiency organization and resources.	C54 Formalizing proposals on new financial mechanisms.

Source: the authors.

More specifically, the program was coordinated:

- on the Chinese side by the Hubei Province Construction Department (Ms. Liang Xiaoqun, Design and Science and Technology Division), Huazhong University of Science and Technology (School of public administration), the Wuhan City Energy Efficiency Bureau, and the Wuhan Municipal Bureau of Land Resources and Housing Management; and
- on the French side by the Agence Française de Développement (Mr. Nils Devernois) and the team of experts placed under its authority, with the collaboration of Mr. Liu Yazhong.

Team A – technical and economic analysis, coordinated by the French consultancy firm TERAO (Mr. Michel Raoust in France and Mr. Aymeric Novel in China) – consisted of members from the Science and Technologies Department of the Wuhan Architecture Committee, the school of architecture and urban planning, Huazhong University of Science and Technologies, the Wuhan Energy Efficiency Bureau, the Institute of Architecture and Design, and Zhongnan Institute of Construction and Design.

Team B – institutional and organizational issues, coordinated by an independent consultant (Mr. Bernard Laponche) – consisted of members from the Huazhong University of Science and Technologies School of Public Administration and the Wuhan Municipal Bureau of Land Resources and Housing Management.

Team C – financing and investments, coordinated by the French consultancy firm ICE (Mr. José Lopez) – consisted of members from the Huazhong University of Science and Technology school of public administration, the Wuhan Boshi (literally "energy and environment") investment company, Mingsheng Bank and Zhaoshang Bank.

2.4.3. *Coordination workshops and meetings*

The research program began in the third quarter of 2006 with the signature of the partnership framework agreement, and continued until the fourth quarter of 2009. It was punctuated by regular coordination and synthesis meetings, which were vital to the proper advancement of the program. These meetings were spread out throughout the duration of the program, on average three times a year, usually held during a visit to China by all or part of the team of French experts. These meetings notably enabled:

- the design and joint implementation of the program methodology, which was the subject of a document containing a detailed inventory of basic tasks and recommendations on how to complete them (this document was written in English and Chinese);
- the launch of the program (October 2006), with all that it entailed in terms of the learning curve and the difficulties getting teams from not only diverse disciplines and origins (civil servants, academics, engineers and technicians, bankers, etc.) but also different cultures;
- the presentation and coordination of progress in research by three groups at different stages of advancement in the project;
- the training of team members [7] to complete the program;
- training in how to conduct energy audits (visit by P. Romanoz in December 2006); and
- training in the use of computer simulation models of energy efficiency in buildings (TERAO consultancy firm, A. Novel, September 2008).

Furthermore, in November 2007, members of the Chinese team came to Europe to work with the French team and visit concrete examples of work done in France, Denmark and Germany.

[7] Faced with the need to conduct energy audits and simulations, these training courses were open to members outside the team.

In addition to these regular exchanges, three main workshops or seminars were held during the implementation of the program:

- a workshop in Wuhan on March 22 and 23, 2008, brought together nearly 80 people, including representatives of the city and various provincial administrations. During this workshop, the Chinese team presented the progress that had been made in its research, and the French team presented various energy efficiency schemes in buildings in five developed countries.[8]
- a conference presenting the results of the entire program was held in Wuhan on May 12 and 13, 2009, under the auspices of the Ministry of Housing and Urban and Rural Development. Nearly two hundred people attended the workshop, including concerned representatives of the main cities in the Yangtze climate region.[9]
- the Sino-French Circle on Energy Efficiency in Buildings met in Paris from October 17 to 24, 2009. This meeting allowed the participants, including high officials from China, to discuss diverse experiences, identify obstacles to overcome, and determine the desired guidelines to foster the establishment of large-scale energy efficiency policies.

[8] As mentioned previously, this investigation and inventory work, requested by the Chinese team, was conducted in partnership with the IEA (see AFD and IEA, 2008) and with the participation of the Swiss Federal Institute of Technology Zurich (ETH) and the Fraunhofer Institut für System und Innovationforshung (ISI) based in Karlsruhe (Germany).

[9] The conference proceedings were published in 2010 by the AFD (see AFD, 2010). The Chinese team also published a document in Chinese during the same timeframe.

FOCALES

Part Three

3. Techno-economic analyses and assessments: toward a large-scale project

Preamble

A large-scale building retrofitting project implies making standard improvements to a large number of targets. These improvements must be attainable in current market conditions and must enable substantial energy savings and lower operating costs. It is not a project-by-project approach, at least during the research phase.

It is also appropriate to define which targets are suitable for a large-scale program. In our program, the research focused on tertiary buildings (called "public buildings" in China) rather than housing. In China, the phrase "public building" is used to designate all buildings that are not housing. The phrase does not express a distinction between the public and private spheres, as it typically would in France. The choice of this target is understandable when one considers the question of financing a large-scale program. Indeed, in the current state of lending conditions and risk acceptance by banks, the number of owners – potential borrowers – involved must be limited, and therefore a maximum of buildings to be retrofitted must be grouped together in a minimum of entities. Housing units are therefore poor candidates. Public buildings, however, can provide the appropriate configuration. In addition, the smallest of these buildings are often destined to be torn down and replaced by taller buildings. This is why large public buildings were chosen as the appropriate target for this type of program.

In order to define optimal improvements to be made to existing large public buildings, it is necessary to establish a techno-economic description of the types of use, building size, state of the building envelope, and the electrical systems and temperature control systems initially installed. Indeed, any retrofitting approach – whether local (single building) or more comprehensive (building stock) – is based on precise knowledge of what exists. First, a rigorous energy diagnostic must be conducted on the building stock. Then, a series of successive "close ups" can refine knowledge of energy consumption and the causes of energy inefficiency. Once these causes have been revealed and sorted by order of importance in the final bill, the energy efficiency gains can be calculated to quantify the impacts of such a program. The work estimating gains and their associated investment costs must be done on a representative sample of all the buildings targeted by the approach. On this basis, a realistic extrapolation of the results can situate the challenges for the large-scale retrofitting program.

3.1. Description of the approach

As was the case when elaborating the methodology, the approach adopted is organized in successive phases reflecting the logic set forth in the introduction. The main phases were as follows:

- establishment of the building stock typology. This typology is composed of general statistics on the built-up area, final energy consumption, construction materials used, and typically installed equipment. At this stage, the data provide orders of magnitude.
- the obtention of more detailed statistics based on surveys conducted on a smaller sample of approximately 400 representative buildings in the "large public building" category. The surveys, more precise than general statistics, provide more information on architectural parameters, equipment diversity, and representative final energy consumption intervals for each type of building. At this stage, the data allow one to identify the most "energy guzzling" buildings, and one can begin to connect energy consumption, building use and equipment.
- within this sample set of buildings, 20 to 30 buildings were selected for complete energy audits, true consumption diagnostics (the owners' approval was needed). This type of audit provides exact knowledge of consumption in the building concerned, and a breakdown of this consumption by use. This consumption profile is primordial because it allows improvements to be prioritized.
- choice of a method by which to calculate estimated potential energy savings. Indeed, once the diagnostic is complete, one must be able to sort improvements based on effectiveness. For this, energy savings must be calculated. Dynamic thermal simulation software must be chosen based on the software capacity and ease of use by local actors.
- estimate of the potential energy savings and investment costs associated with the technologies employed. Based on the audit results, an initial simulation serving to confirm or fine tune the energy diagnostic to be conducted. With this baseline, the impact of different measures such as exterior insulation, interior insulation, new windows, improved regulation, a new chiller, etc., to be calculated. This work makes it possible to determine the effectiveness of different technical combi-

nations. By combining these results with investment cost data, one can determine suitable programs for each type of building to generate adequate energy savings with an acceptable payback time for the investment.

- calculation of results for representative buildings, then careful extrapolation if the climatic and statistical similarity between the extrapolation zone and study zone can be proven.

3.2. Building typology and characteristics

The approach set forth above takes place in a linear fashion. We shall use the research program in Wuhan to illustrate its application. We can note the extent to which the theoretical method was able to be applied, and the difficulties encountered.

3.2.1. *Existing building stock typology: overall structure of the stock*

This typology covers many elements. First, it defines the types of buildings that make up the building stock and provides some basic data.

The total built-up area for the city of Wuhan covered 182,735,500 sq. m. in 2006. Public buildings (non-residential, *i.e.* commercial, government and industrial buildings) accounted for 74,814,700 sq. m., or 41% of total building stock surface area. Since 2000, the built-up area had seen an annual increase in the proportion of public buildings (rising from 29% in 2000 to 39% in 2006). The trend is therefore for the proportion of public buildings to grow compared to housing.

Developers build above all housing (85% of annual construction surface area), followed by commercial buildings.

Public buildings (74,814,700 sq. m.) are distributed as follows:

- administrative buildings: 6.9% (5.152 million sq. m.);
- hospitals: 4.2% (3.126 million sq. m.);
- luxury hotels: 2.3% (1.741 million sq. m.);
- educational facilities, including university housing: 28.6% (21.41 million sq. m.); and
- commercial and other buildings: 58% (43.38 million sq. m.).

Buildings built prior to 1980 were often made of 240 mm brick walls. After 1980, the brick was replaced by 190 mm hollow brick, sand-lime bricks, shale bricks and silicate blocks. These new construction materials take into account some recycling, but not energy efficiency. Simple untinted 3-5 mm single-pane windows are still the most widespread model in existing buildings. Most roofs are not insulated.

In regard to the public building stock, the data on surface area distribution are incomplete, and records of construction materials used, building age, and building facilities are not kept.

3.2.2. *Survey sample*

A survey of 389 buildings was done to determine a more precise typology. The total area included in the survey was 3,963,497 sq. m. (or approximately 5% of the total public building stock). Within this sample, 47% were administrative buildings with a floor area greater than 3,000 sq. m., and 13.4% were large public buildings with floor area greater than 20,000 sq. m. This first survey determined the consumption intervals for each type of building. Among these 389 buildings, 106 were verified in detail, and 23 were the subject of energy audits.

This advance in data precision illustrates a crucial element in this method: gathering information and information reliability. The lack of reliable data comes from a lack of consumption measurements and peopled skilled in monitoring buildings during use.

Table 6 *Building Classification by Age, Construction System and Type of Air Conditioning (Wuhan)*

Year Built				Structure				Type of Air Conditioning		
1970s	1980s	1990s	2000s	Brick and Concrete Walls	Concrete Column-beam	Frame-shear	Steel Framing	Individual	Central	Other
21	64	162	130	143	202	3	3	268	116	5
5.4%	16.5%	41.6%	33.4%	36.8%	51.9%	0.8%	0.8%	68.9%	29.8%	1.3%

Source: Hubei Provincial Statistics Bureau.

One can see that a majority of buildings have individual air conditioning (69%) and that there is a large proportion of recent buildings (75% built after 1990). Most of these buildings are not insulated. The basic fuel is electricity, natural gas or liquefied natural gas.

Among the 106 buildings verified, 5 were eliminated because of erroneous energy consumption values. In all, the data from 101 buildings were confirmed as usable: 51 administrative buildings and 50 large public buildings. Tables 7 and 8 classify these buildings based on their heating, ventilation and air conditioning (HVAC) equipment.

Table 7 *HVAC Equipment in Administrative Buildings*

Individual Air Conditioning	Air-to-Air Heat Pump	Chiller + Boiler	LiBr* + Oil Boiler	Individual A/C + Air-to-Air Heat Pump
56%	14%	20%	2%	8%

** Lithium Bromide: a substance generally used in absorption chillers (called LiBr chillers by extension).*
Source: Hubei Provincial Statistics Bureau.

Table 8 *HVAC Equipment in Public Buildings*

Chiller + Boiler	Individual Air Conditioning	Individual A/C + Air-to-Air Heat Pump	Individual A/C + Chiller + Boiler	Chiller
68%	2%	2%	4%	8%

Multi-Split A/C + Individual A/C	Cold Storage + Boiler	Air-to-Air Heat Pump	Chiller + Cold Storage	LiBr Chiller
2%	2%	4%	4%	4%

Source: Hubei Provincial Statistics Bureau.

Most administrative buildings operate with individual air conditioning (decentralized systems). Most public buildings, however, operate with chillers and boilers (central systems). The terminal units are primarily fan coils or all-air systems (variable air volume – VAV). All kinds of lighting were found (T5, T8, incandescent, halogen). The statistical data on the 389 buildings surveyed are fairly complete and describe the main characteristics well.

3.2.3. *Conclusions regarding the collection of descriptive data on architecture and systems in the building stock*

One can note that the statistics on built-up surface area are relatively incomplete on the scale of the city building stock. Nevertheless, a useful picture of the approximate distribution of surface area can be drawn up:

- housing accounts for a considerable proportion of built surface- 60%. This means that a great deal of work remains to be done to retrofit the entire building stock (the multiplicity of owners is an issue).
- among public buildings, nearly 60% of the floor area falls under the "commercial building" category, which most probably belongs to mostly private owners. However, in a country such as China, it is probable that the most appropriate candidate for a pilot program is governmental in nature.

Looking at just the statistics on surface area already shows non-negligible constraints on the full exploitation of energy savings potential by retrofitting the existing building stock.

The only way to get an idea of the construction products and HVAC systems installed in existing buildings is to select a sufficiently large sample to deduce trends. We were able to determine the following:

- most buildings that were candidates for the large-scale retrofitting program were, paradoxically, relatively young buildings (built after 1990, or even after 2000). However, in China, 10 years is not an unusual lifespan for many installations.
- a clear trend was seen in installed systems: government buildings tended to be equipped with individual air conditioners, whereas other buildings tended to use central systems. This is an important difference: individual systems will depend more on direct use by occupants than central systems that, for their part, offer greater energy saving potential by optimizing regulation.

3.3. Energy consumption in buildings

3.3.1. *Study of the sample of 389 buildings, initial evaluation of consumption*

Once the building stock has been described with the available statistical data, one can enter into the heart of the matter by studying energy consumption in existing buildings. Final energy consumption will be studied first.

When it comes to the building stock as a whole, we have only very little general information. It is, however, useful to determine the bounds for value intervals using national statistics and previously conducted local studies (when they exist). The information that we had is therefore presented below.

National statistics

Consumption in public buildings in China is on average 180 kWh per sq. m. per year of final energy. Depending on the type of building, consumption varies between 70 and 300 kWh per sq. m. per year.

Existing municipal statistics

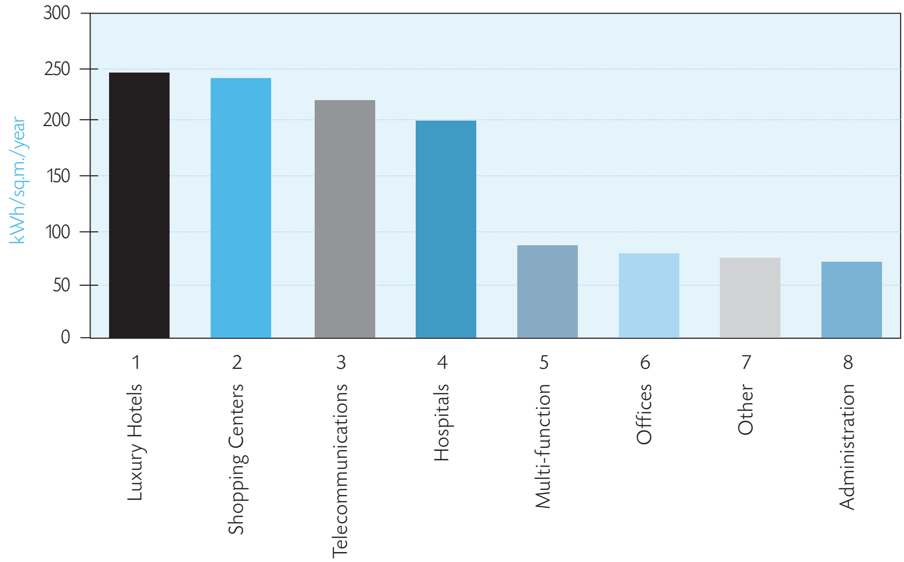
Electricity consumption in buildings in Wuhan is 36% greater than the national average. Between 2001 and 2006, it rose by 17%.

The share of air conditioning in building energy consumption in Wuhan in 1999 ranged between 22% and 81%. The average share in Wuhan was approximately 44%. Total operating costs were between 37 and 285 RMB per sq. m. per year; the share devoted to air conditioning was therefore comprised between 20 and 125 RMB per sq. m. per year.

To have more data on energy consumption, the 389-building sample was subject to a series of surveys. In order to eliminate erroneous values and fine-tune the surveys, the sample was then cut down for new surveys on only 101 buildings.

Consumption varies significantly based on building category. Table 9 shows consumption broken down by the amount of energy devoted to HVAC (*i.e.* temperature control) and use specific to building activity.

Figure 23 *Final Energy Consumption by Type of Building in Wuhan in 2008 (in kWh/sq.m./year)*



Source: Wuhan Municipal Construction Department / Hubei Province Institute of Architecture, Science and Design.

Table 9 *Annual Final Energy Consumption by Type of Building in Wuhan in 2008 (in kWh/sq.m./year)*

Type of Building	Surface Area Studied (sq.m.)	Total Consumption (kWh/sq.m./year)	Water Consumption (ton/year)	Share of HVAC in Total Bill (%)
Luxury Hotels	389,349	244	8.5	29
Shopping Centers	211,643	239	1.4	35
Telecommunication Buildings	91,441	220	1.3	22
Hospitals	127,100	199	5.3	42
Multi-function Buildings	194,800	84	1.1	43
Office Buildings	352,023	77	0.4	37
Other	67,000	73	5.1	29
Administrative Buildings	656,134	71	2	44

Source: Wuhan Municipal Construction Department / Hubei Province Institute of Architecture, Science and Design.

An examination of Table 9 shows that the buildings that consume the most energy are luxury hotels, telecommunications buildings, hospitals and shopping centers, consuming on average 200 kWh/sq.m./year or more. The other buildings, notably offices and administrative buildings, while institutionally best suited to a large-scale retrofitting program consume less energy with consumption below 100 kWh/sq.m./year.

What is more, the proportion of HVAC use in total consumption varies between 30% and 45%. Finally, less than half total consumption could be targeted for reduction through thermal measures. The exception is “telecommunication” buildings, where HVAC accounts for only a 22% share of consumption. This is caused by use: in the case of telecommunications, there is high electricity use for data processing (servers, etc.).

Hotels, while consuming the most, use only roughly 30% of final energy for HVAC. They show a specific high use of energy: domestic hot water.

3.3.2. *Energy audits: detailed knowledge of energy consumption*

Energy audits are indispensable to know specifically how energy consumption breaks down by use, and compare energy consumption calculations to measured consumption, which serves to confirm the calculation method used, which will then be used to predict energy savings from interventions on the building envelope or equipment.

Conducting an energy audit amounts to performing a diagnosis of energy use. The characteristics of energy consumption over time and by use must be studied and linked to the technical characteristics found on site. The information obtained in this way will be much more precise than the information from the surveys discussed above. Real consumption values, whether these values are consistent from year to year, and how the numbers break down by use are known.

The general audit approach

We shall describe the typical elements of an audit method, and then illustrate it with an example.

An energy audit must define the elements that determine:

- energy needs, *i.e.* climate, architectural data, construction characteristics, type of activity, mode of occupation, inside equipment, ventilation system, etc.; and
- consumption, *i.e.* production, regulation (intermittent management, recommed-ed temperature settings, etc.), distribution networks, emissions.

1) Architectural data and construction characteristics:

- year built;
- ground plan;
- orientation of main facades;
- shading from neighbourhood;
- shape, compactness;
- building use;
- proportion of windows to walls;
- insulated walls: Y/N, thickness and material, even the U-value[10] of losses previously calculated by the design institute;

[10] Heat transfer coefficient expressed in W/m²°C.

- description of windows (window frame, type of opening, solar shades, etc.);
- natural ventilation, mechanical ventilation;
- number of split air conditioners per side;
- surface area data (footprint, net floor area – NFA, usable floor area – UFA).

2) Occupation scenarii:

- constant occupation, hourly schedule;
- staff and visitors, distribution throughout the day;
- vacation;
- equipment influencing inside contribution (lighting, computer equipment, other);
- ventilation rate;
- comfort parameters (temperature, installation use rate) and recurrent reports of annoyances (if any).

3) Technical installations:

- low-voltage electrical panel (LVEP) + back up (presence of a generator, etc.);
- installed lighting power in W/sq.m.;
- computer equipment (laptops or desktops, types of monitors, etc.).

Heating:

- description of the technology;
- typical operating temperatures (departure, return);
- power and nominal yield;
- position;
- type and age of key components (burner, motors, pumps, etc.);
- ventilation of utility areas;
- type of fuel.

Cold Production:

- description of the technology;
- typical operating temperatures (departure, return);
- power and nominal yield;
- position;
- type and age of key components (compressor, motors, pumps, etc.);

- ventilation of utility areas;
- type of fuel.

Cooling Circuit:

- pump power, nominal output;
- number and position of towers.

Emitters:

- electric power of fan coil units;
- individual splits;
- chilled beams or other induction terminals.

4) Distribution circuit:

- power of heat and cold pumps;
- nominal output;
- location of start point, distribution column, and secondary branches;
- whether or not there is a balancing system.

5) Installation operation:

- run by the manager? automatic?
- times turned on? is heating anticipated?
- recommended temperature?
- pace adjusted to outside temperature (with what logic)?
- supplements in addition to the main installation?

6) Weather data:

- temperatures;
- solar irradiation;
- rainfall;
- available weather records.

7) Study of fuel consumption records:

- over several years;
- notable variations?
- relative importance of heat and cold (breakdown of consumption);
- consistent behaviour from one year to the next?

- is mid-season very different? (describe use: that of a hotel will, for example, be very different from that of an office building);
- monthly load rate (AC/heating % of nominal power used to identify over/under sizing);
- if several LVEP connections, possibility of revealing several services;
- extrapolation from bills of items responsible for consumption peaks (cooling tower, etc.);
- operating assumptions;
- relative proportion of HVAC consumption in the total bill for the specific relative importance of heating to electricity.

8) Consumption costs:

- operating cost based on bills;
- cost of maintenance (the more the cost of electricity increases, the more the operating cost of auxiliaries is high compared to gas energy production; this can favor flowrate operating modes with greater temperature differences).

9) Interviews with managers:

- recurrent maintenance problems;
- recurrent complaints about inadequate comfort.

10) On-site measurement possibilities:

On-site measurement of ambient parameters and at equipment operation points provides a great deal of information. Doing so requires one to have invested in measurement equipment, however, and this can be costly.

Quality of the interior environment:

- temperatures;
- humidity;
- CO_2;
- luminosity.

Building and HVAC systems:

- temperatures and water and air flowrates from hydraulic and air circuits: balance problems, leaks, unwanted by-passes in the AHU, operation at high output, verification of operating temperature compliance with design of water and air installations;

- measurement of real recovery efficiency of dual-flow ventilation;
- infrared camera for thermal bridges, test of the false door for air tightness;
- smoke/fume measurements for the quality of furnace combustion (O_2, CO_2, CO, combustion yield, excess air, etc.).

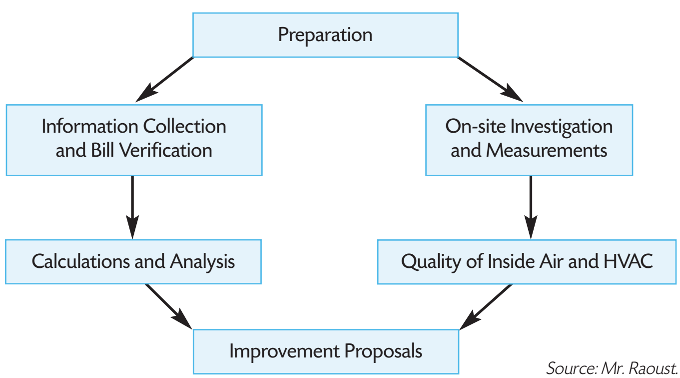
11) Problems habitually encountered during energy audits in China

- Awareness and behaviours;
- Lack of professional energy managers;
- Lack of basic building data;
- Incomplete or missing consumption measurement systems.

The last two points imply an interest in simulating the building and performing an audit, simultaneously.

12) Audit Methodology Schematic

Schema 1 *Audit Methodology Schematic*



Source: Mr. Raoust.

Box 1 *Sample Application of the Audit Methodology*

We illustrate the methodology with the example of the audit of the Wuhan City Energy Efficiency Bureau building.

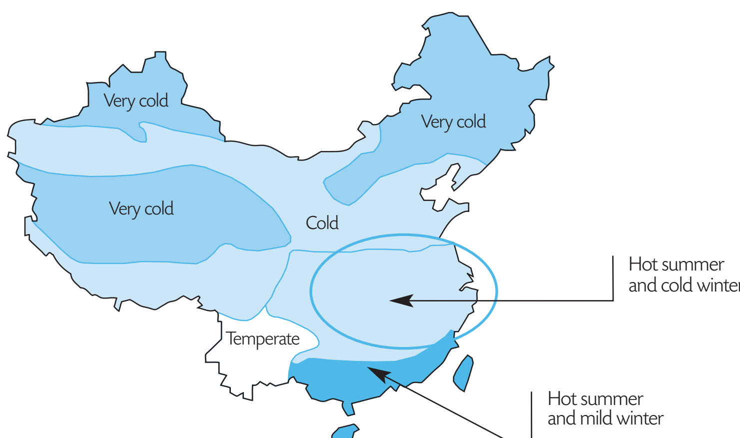
First, we shall present the weather data for the city.

Wuhan weather data

Before analyzing any building in the city, one should describe the climate in which it is found; this allows one to anticipate many characteristics.

China covers a vast territory that encompasses several climate zones, as illustrated in Map 1.

Map 1 *The Different Climate Zones in China*



Source: Lawrence Berkeley National Laboratory.

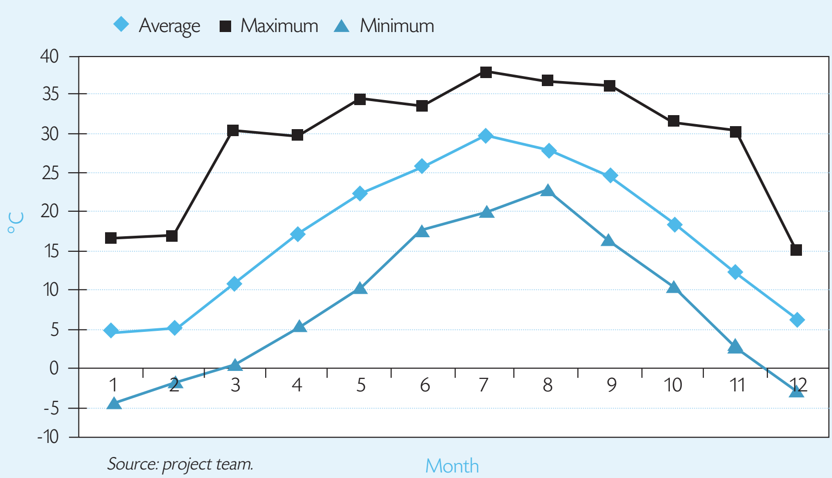
China stretches over many latitudes and therefore contains climates ranging from extreme cold (it can be 40°C in winter in Xinjiang or Heilongjiang, the two northernmost provinces) to extreme heat and humidity (Yunnan province, in the south, is close to Vietnam and Laos with a similar mono-seasonal climate: temperatures are above 30°C for most of the year).

•••

Wuhan is located in the center of the country, in the climate zone (blue circle). Temperature control design must therefore take into account summers with high demand for air conditioning and winters that must not be ignored because temperatures can sometimes fall below freezing.

Logically, there will therefore be room for energy savings from both air conditioning and heating. Admittedly, heating expenses account for roughly 60% of air conditioning expenses in the region.

Figure 24 *Monthly Average Outdoor Temperatures in Wuhan (in °C)*



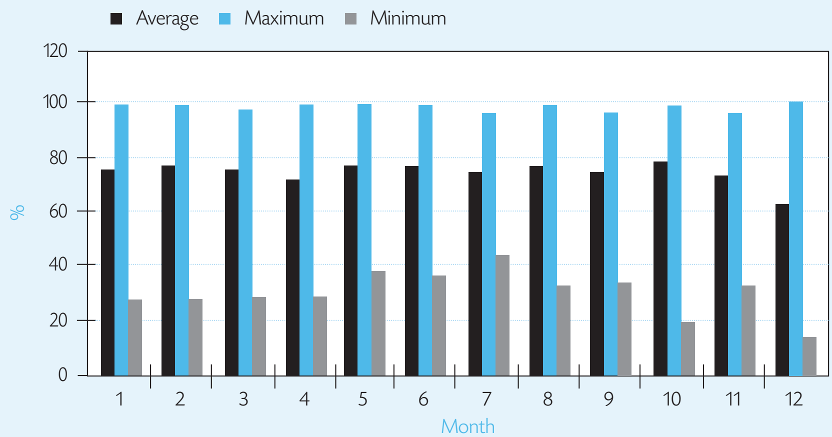
Source: project team.

The maximum monthly average temperature in Wuhan is 29.8 °C, with maximum temperatures reaching 38.8°C. This last figure illustrate the high temperatures that can be encountered (in July).

In winter, January has the lowest average temperature: 4.6°C. The lowest recorded temperature is, for its part, -3.9°C. Heating is therefore increasingly used in the region. It should be noted that during Mao's era, it was decided that all cities south of the Yangtze river – one of the two longest rivers in China, ahead of the Huanghe – would not be entitled to heating.

Relative and absolute humidity

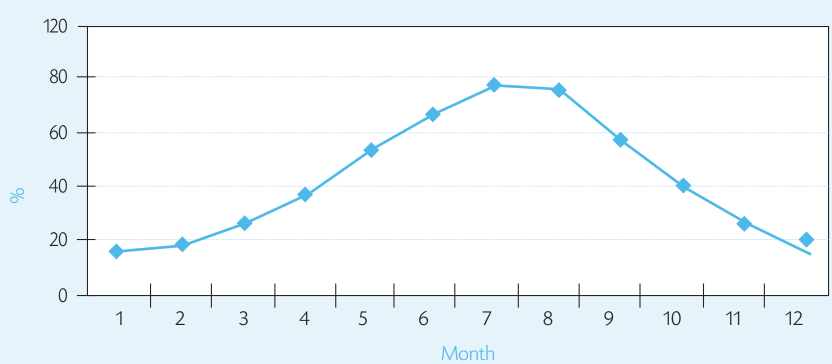
Figure 25 *Relative Humidity in Wuhan (in %)*



Source: Hubei Provincial Statistics Bureau.

We can see that relative humidity is fairly high. The monthly average is relatively consistent throughout the year, at approximately 75%. It is not rare for the air to be saturated with moisture because the maximal values are all close to 100%.

Figure 26 *Absolute Monthly Humidity in Wuhan (in %)*



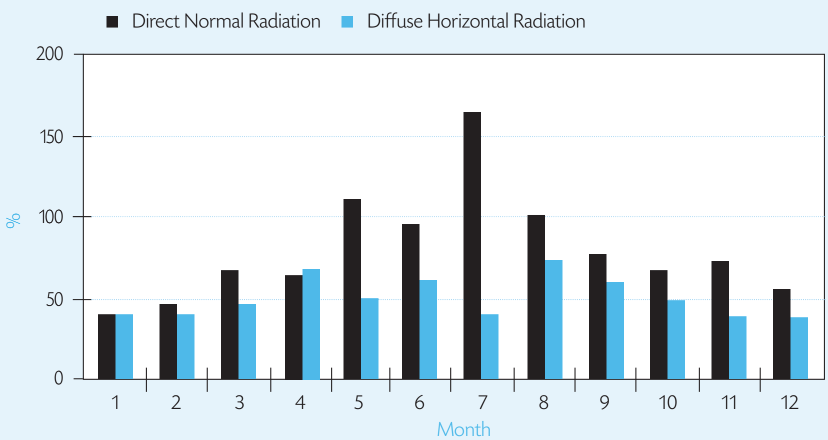
Source: Hubei Provincial Statistics Bureau.

•••

In correlation with the preceding observations, one notes that the climate in Wuhan is effectively very humid, in particular in the summer when absolute average humidity reaches 19.3 g/kgda.

Sunshine

Figure 27 *Average Monthly Sunshine in Wuhan (in kWh/sq.m)*



Source: Hubei Provincial Statistics Bureau.

There is a great deal of sunshine in the summer. One major energy efficiency challenge in the summer is controlling direct sun exposure.

In order to illustrate the work done during the energy audit, Appendix 1 presents the data collection for the audit of the Wuhan City Energy Efficiency Bureau building.

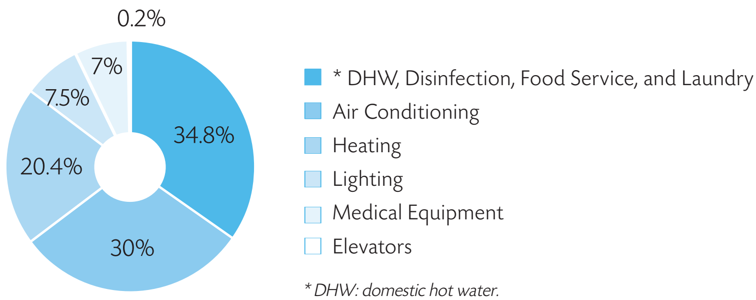
3.3.3. *Typical consumption profiles (hospitals, offices, luxury hotels)*

In order to illustrate the differences in consumption profiles between building types, we give the profiles established for hospitals, offices and luxury hotels.

Hospitals

The consumption profile by use for a large hospital is presented in detail in Appendix 2. This case is particularly important because a building such as this belongs to the "energy guzzling" category and has very diverse uses, as illustrated in Figure 28.

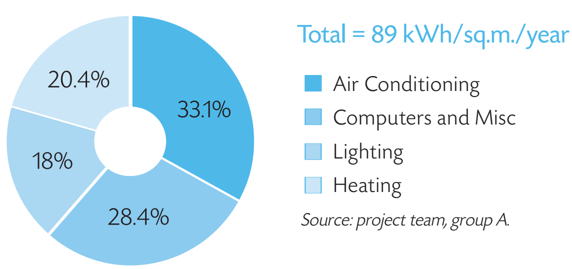
Figure 28 *Breakdown of Final Energy Uses in the Hubei University of Science and Technology Hospital (in %)*



** DHW: domestic hot water.*
Source: project team.

Office buildings

Figure 29 *Distribution of Final Energy by Use for the Hubei Province Department of Education (typical office), in %*

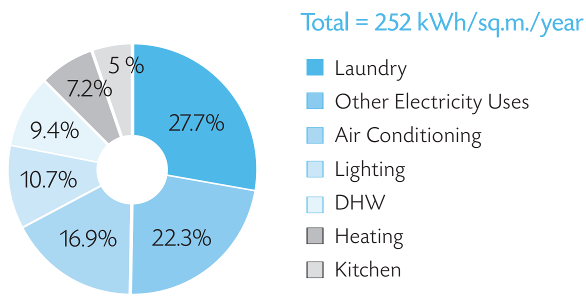


Source: project team, group A.

There are much fewer uses than in the hospital. Indeed, while the relative weights of heating and air conditioning are fairly similar to those in the hospital, lighting is the major challenge here. Similarly, computer use accounts for a considerable amount of total consumption. As a reminder, lowering these two items could also significantly reduce air conditioning costs.

Luxury Hotels

Figure 30 *Breakdown of Final Energy by Use for the Shangri-La 5-Star Hotel, in %*



Source: project team, group A.

This case is very different from the previous one. The typical characteristics of the building type emerge: a large share of consumption linked to laundry (clean sheets), and high miscellaneous electricity use. Of course, air conditioning remains an item to address (this is a constant in buildings in Wuhan); heating, however, is a much smaller item in the total bill than in the case of offices and hospitals.

3.4. Energy consumption calculation tools

Calculation tools are needed to study consumption in existing buildings in detail and above all, estimate the potential energy savings specific to each retrofitting technique and to each combination of improvements. These tools are dynamic thermal simulation software capable of reproducing with sufficient accuracy the dynamic energy balances of buildings based on the numerous parameters that influence them, and notably those that one wants to modify (building envelope characteristics, HVAC equipment characteristics, electricity systems, and the use/regulation of all this equipment).

In the context of our program, we needed to find a tool that would be reliable, sufficiently easy to use, and use a language and system of units compatible with Chinese users. The tool also needed to have a vast library of weather data. We chose the EnergyPlus software and its graphic interface, DesignBuilder. EnergyPlus, developed in the United States by the Lawrence Berkeley Laboratory, is among the best validated software in this field. It is frequently updated, notably as concerns the libraries of window and equipment characteristics. This type of tool is above all a design tool and an aid for the rational decision making needed to optimize a retrofitting program. Here, we shall briefly describe what is taken into account: three categories of parameters, which correspond to three potential areas for improvements, *i.e.* the building envelope, interior gains, and active systems.

3.4.1. *The envelope*

3D Building geometry, facade design and zoning of premises

To faithfully reproduce the heat balances of a building, one must reproduce the data on surface areas, slopes and orientation, or in other words correctly reproduce the building geometry. Photos 1 and 2 show the real building and its digital model (Hubei Province Department of Education building).

Photos 1 and 2 *3D Model of the Hubei Province Department of Education Building*

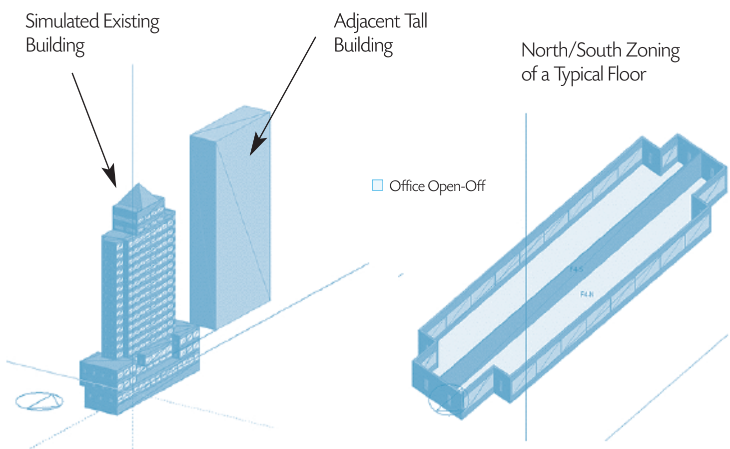
1

2

Photo credit: authors.

The building faces north-south, and has a high proportion of windows – approximately 50% of its main facades and only 7% on the eastern and western sides. It is also important to take into account the influence of surrounding buildings and determine, within the building, the appropriate thermal zones. This last element consists of grouping, in the same energy balance, the premises that are the same from the standpoint of thermal behaviour. They must therefore have the same orientation, the same construction products, and the same quantity of internal heat sources.

Schema 2 *3D Model of the Hubei Province Department of Education Building*



Source: project team, group A.

Close to this building is a large office tower; it must be represented to take into account the solar shade effect. Finally, the vast majority of premises are similar in regard to internal contributions and construction products, so it is appropriate to zone them according to north/south exposure alone.

Thermal properties of construction Products

Opaque walls

The composition of opaque walls allows us to know the thermal insulation coefficient, illustrating the insulation power of the ensemble. In the case of Wuhan, the aim is to show the interest and possibility of adding insulation, preferably exterior insulation. Schema 3 illustrates the influence of insulation on the heat loss coefficient (U).

Schema 3 Influence of Insulation on the Wall U-Value of the Hubei Province Education Department Building

Without insulation:
U = 2.2 W/sq.m. K

Interior insulation – 5 cm
glass wool:
U = 0.7 W/sq.m. K

Exterior insulation – 5 cm
glass wool:
U = 0.56 W/sq.m. K

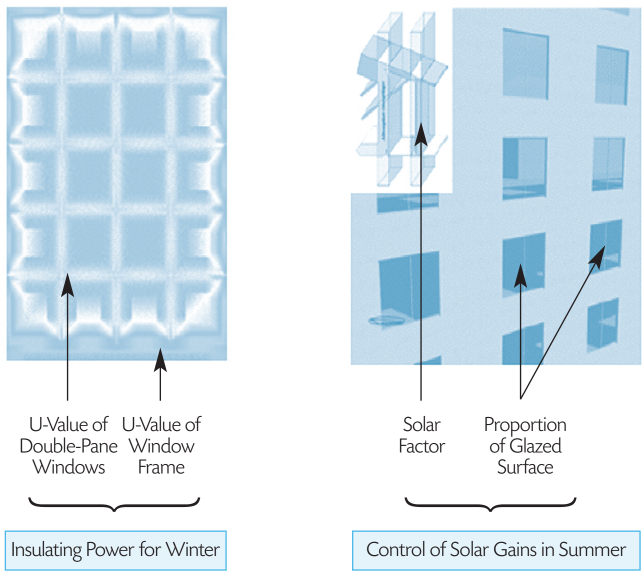
Source: M. Raoust.

Schema 3 illustrates the effect of laying 5-cm glass wool on the walls' insulating properties. A typical thermal bridge of the wall/slab connection is represented to distinguish between exterior/interior insulation options. Undoubtedly, at first, even interior insulation would provide great benefits by reducing conduction losses through walls by three. External insulation obviously gives better results but we shall see later that installation can be complicated, especially on very tall existing buildings.

Glass Surfaces

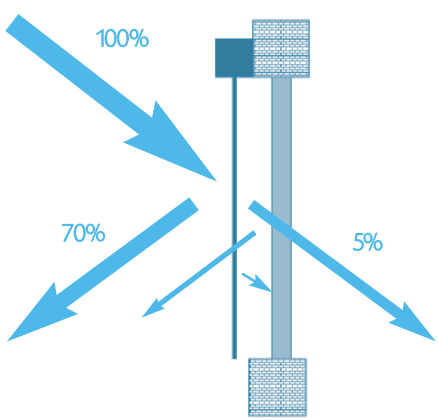
In a climate such as Wuhan's, glass surfaces make up the most important element in facade design because they have a direct impact on the summer energy balance (through direct solar contributions) and winter energy balance (through their insulating power). In addition, the proportion of glass surface for each orientation is normally an architectural parameter to optimize. In the case of existing buildings in Wuhan, and in China generally, this parameter is rarely optimized on a case by case basis. As a result, we often find large proportions of glass surfaces, single-pane windows, without solar protection or with only light inside curtains. This corresponds once again to the construction norms that concern the vast majority of the existing building stock examined. The improvements will therefore deal with the intrinsic performance of windows (see Schema 4) and the promotion of more effective solar protection (outside solar protection; see Schema 5).

Schema 4 Improvements in Window Performance on the Hubei Province Department of Education Building



Source: M. Raoust.

Schema 5 Improvements in Window Performance on the Hubei Province Department of Education Building



Source: M. Raoust.

Exterior sun shades allow little or no solar energy into the premises, and therefore offer much better protection than inside sun shades. This result is easily proven with simulations. This simplified schema illustrates the fact that a small amount of incidental solar energy will be transmitted into the premises. The phenomenon of multiple reflections of the sun's rays between the blinds and the window along with the window's thermal and light properties are taken into account.

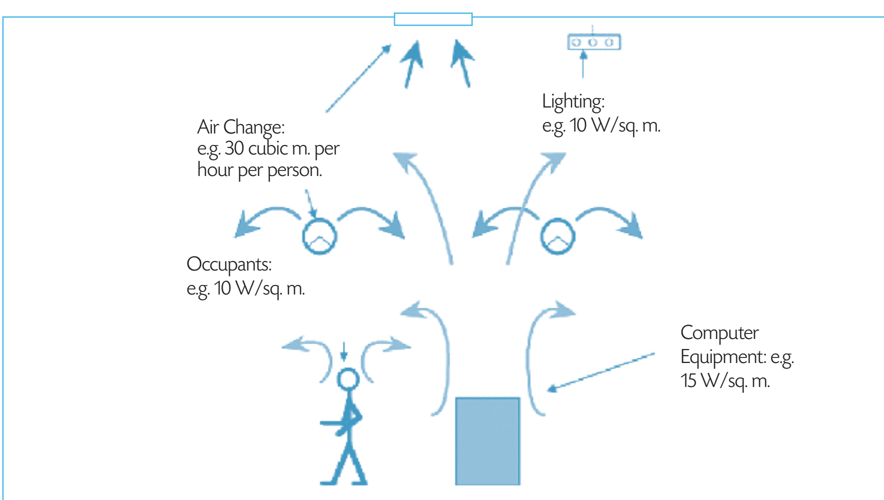
3.4.2. *Internal contributions*

The various sources of internal contributions

Within the building premises, there are various heat sources. They need to be taken into account because, in many cases, they have a strong influence on energy consumption (and on heating and cooling costs) and because many of them are direct sources of electricity consumption. Reducing them therefore has double impact. One example of this principle is lighting. Lowering the installed wattage of lighting by using low-consumption lamps is an action that reduces both the electricity consumption of lamps and air conditioning costs.

In a typical office, the sources of internal heat are illustrated in Schema 6.

Schema 6 *Internal Heat Sources in a Building*



Source: M. Raoust.

Their impact on energy efficiency

Certain heat sources are 'free' because they do not consume electricity; others are not:

- *one free source of heat* is the occupants. Indeed, the human body puts off heat and humidity. For instance, one adult doing light office work emits approximately 100 W, roughly half of which through radiation and convection (sensible heat) and half through water evaporation (latent heat).
- *sources of heat that consume electricity* are lighting and computer equipment. These sources can in no way be described as "free"; the heat that they emit is directly equal to their electricity consumption. In a predominantly warm climate, it is wise to reduce their consumption.
- *fresh air forms a unique category.* In most cases, it cannot be called "free" because air is brought by mechanical ventilation. In addition, the contribution from air varies according to outside conditions: air can bring cooling or heat, and it can be treated, or not, in the air processing system before the terminals. In mid-season, it is wise to use the cooling power of air to lower temperatures in the building and therefore lower air conditioning consumption. The most economical method is still opening windows (natural ventilation).

3.4.3. *Active systems*

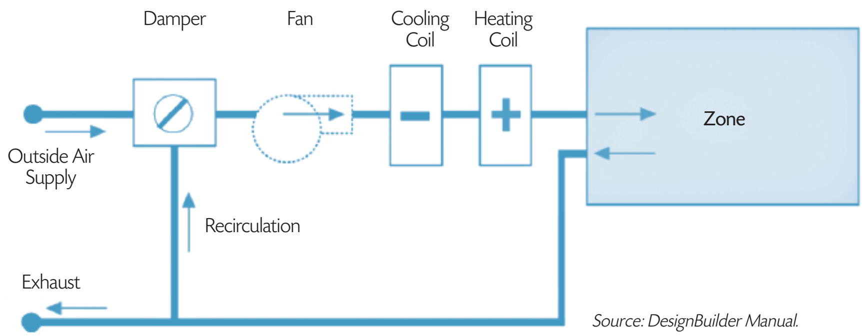
Of course, in a building, the thermal performance of the building envelope partially defines the load on active systems. In the end, these systems are what consume energy. It is therefore indispensable that the calculation tool chosen can faithfully represent the behaviour of these systems. This notably requires the ability to take into account:

- the type of system (all-air HVAC, fan coils, variable or constant output, central or individual system, etc.);
- the type of heat and cold production equipment and their output under different regimes;
- the efficiency of pumps and ventilators;
- the type of regulation.

Schemas 7 and 8 illustrate two types of HVAC systems that can be modeled and that differ in nature due to their advantages and inconveniences: a local fan coil system (see Schema 7) and a VAV-type central system (see Schema 8).

Schema 7 illustrates a fan coil model. It is applied only in one zone and is therefore a local system. It makes it possible to attain the exact desired recommended temperature because it only has to deal with one zone and therefore only one given load.

Schema 7 *Fan Coil Model*



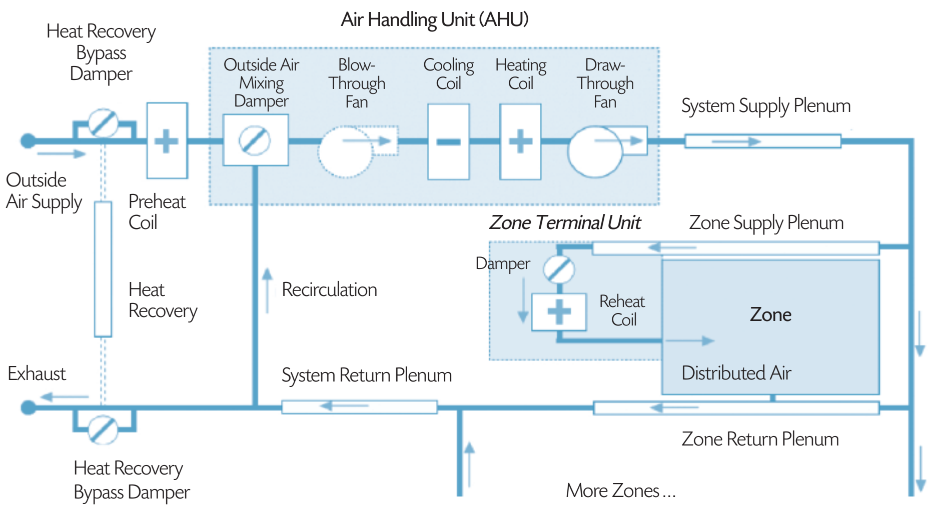
Source: DesignBuilder Manual.

This type of system has one major inconvenience: the consumption of its fans. This is particularly true for the models that we find in existing buildings ten years old or older. This consumption, which is prohibitive for building energy performance, has encouraged the development of new types of terminals, and low consumption fan coils (new generation of motors and variable frequency fans) in new buildings. This state of affairs is important for retrofitting in China because a vast majority of office buildings are equipped with fan coils, as in the aforementioned example of the audit of the Wuhan City Energy Efficiency Bureau building.

The old models are also little optimized for occupants' comfort (air streams are too hot or too cold and poorly distributed throughout the zone). This fact is also important because the feeling of discomfort causes occupants to take awkward corrective actions (*e.g.* open windows, turn up the heat or air conditioning), which have a tendency to worsen the problem rather than resolve it. The system simulations, combined with precise information on building use during the audit, can and must include these facts.

The second model, illustrated by Schema 8, is that of an all-air variable output VAV system. This system is very different from the first because it serves several zones at once. It is composed of an air handling unit (AHU) that first processes the air, for instance by pre-warming it to 14°C. Each zone can then be equipped with a terminal heating unit to attain the recommended temperature precisely in winter.

Schema 8 *VAV System Model*



Source: DesignBuilder Manual.

This system has a major inconvenience, typical of all-air systems: by using air to provide the necessary heating and cooling in an inefficient building, it is necessarily energy guzzling, causing excessive consumption by fans. In addition, in summer, this type of system does not have a terminal unit and therefore blows a certain quantity of cool air to all premises. It can adapt to the local load by varying the output of blown air, but if the diversity in local loads is too great (poor zoning), it will not be comfortable and energy will be wasted. Certain zones could be too cold while others are too hot and the occupants risk opening the windows, or even buying individual air conditioners.

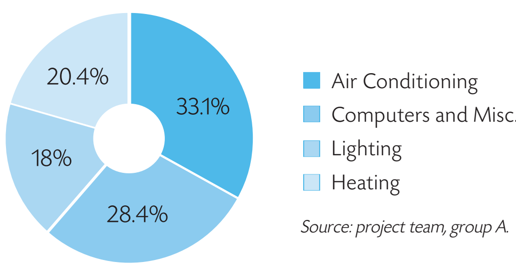
3.5. Applying simulations to energy efficiency retrofitting

3.5.1. *Audit assistance*

In addition to an energy audit, it could be useful to conduct this type of simulation to confirm the data collected and fine-tune the final diagnosis, especially in regard to final energy use. As we saw in the section on energy audits, this information is crucial to establishing a clear diagnosis and proposing suitable improvements. Unfortunately, however, it is often lacking.

Figure 31 shows an example of fine-tuning an energy diagnosis with the assistance of simulations. It uses the case of the Hubei Province Education Department building mentioned above when presenting the raw data from audits.

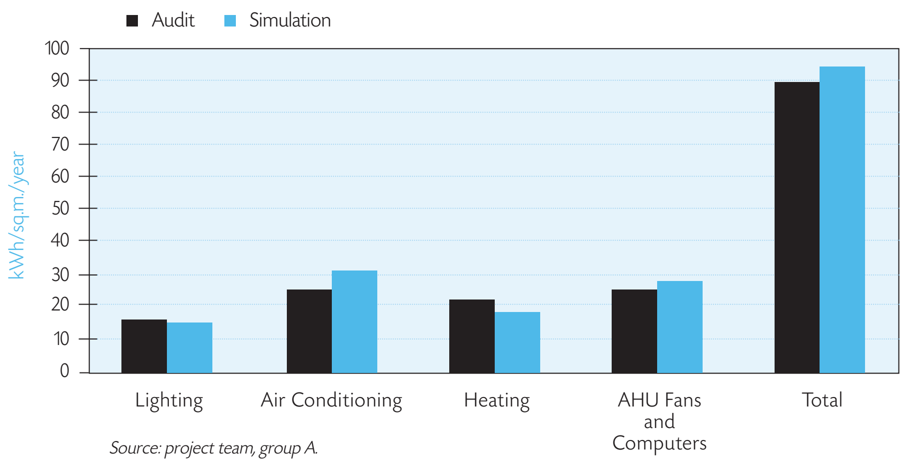
Figure 31 *Distribution of Final Energy by Use for the Hubei Province Department of Education Building (typical office)*



Source: project team, group A.

The simulation can reproduce this result directly from bills and, therefore, the reality of building operations. Figure 32 illustrates the correspondence of consumption items between the simulation and Figure 31.

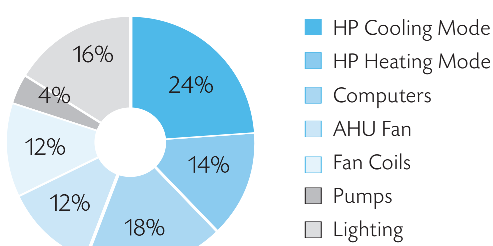
Figure 32 Comparison of Audit Data with Simulation Data



Source: project team, group A.

Once this correspondence has been established, one can examine detailed energy use more precisely through dynamic thermal simulation (Figure 33).

Figure 33 Breakdown in Final Energy Use – Audit Supplement Via Thermal Simulation



Source: project team, group A.

This breakdown sheds light on the previous discussion of the types of systems and lets one quantify them. The building in question has an all-air VAV system for the first three floors, and a new preconditioned air distribution system with terminal fan coils in the rest of the offices (most of the building's total floor area). Heat and cold are produced by four reversible air/water heat pumps. This is not a case of all-electric, a positive point for economic feasibility

Here, one logically sees that the share from AHU fans and fan coils accounts for one quarter of total consumption. There is therefore a real interest, in this case, of improving the efficiency of these fans, or even reducing the air output required by the VAV system by lowering the load by improving the envelope. Similarly, improving the heat pump (HP) yield by replacing it with a new generation HP could bring about considerable savings. Lowering the installed power of lighting and reflecting on the computer equipment are also actions that could directly lower electricity consumption and air conditioning load. In this way, we can clearly see that once a precise diagnostic has been drawn up, the conclusions on improvements to propose are relatively obvious.

Estimated potential energy saving gains, investment costs and gross payback periods

The other advantage to using simulations as early as the audit phase is preparing a very realistic referential on what exists. From this, it is also easy to adjust technical parameters to estimate potential gains in energy savings.

Initially, the techno-economic outcome of each type of intervention must be established. This makes it possible to separate low-cost actions with short payback times from expensive actions with long payback times.

Let us look at the example of the Wuhan Municipal Bureau of Land Resources and Housing Management building. It is a typical office building with final energy consumption of 101 kWh/sq.m./year (according to the audit). Its energy diagnosis is similar to the Department of Education building.

The actions with numerical values are as follows:

On the building envelope

- installing exterior insulation – 5 cm. EPS;
- replacing single-pane windows with clear double-pane windows; and
- installing exterior sun shades.

On active systems and electric systems

- replacing lighting by more energy efficient models;
- improving the electricity distribution and management system; and
- improving the existing air conditioning system (optimizing operations at partial loads, replacing pumps with variable frequency models, cleaning exchangers).

We calculated potential energy savings using the thermal simulation and by comparing information with ESCOs and other local experts specialized in various techniques to improve the active systems typical of the region. The investment costs are based on local prices. We can, for example, give the following representative ratios:

- exterior insulation: 160 RMB per sq. m. of wall;
- installation of clear double-pane windows: 350 RMB per sq. m. of window;
- installation of exterior sun shades: 350 RMB per sq. m. of window;
- solar film on existing windows: 280 RMB per sq. m. of window;
- replacing lighting: 30 RMB per sq. m. of NFA;
- improving the electricity distribution system: 20 RMB per sq. m. of NFA;
- slight improvement (optimization) of active systems: 30 RMB per sq. m. of NFA.

The estimated results are presented in Table 10.

Table 10 *Energy Savings and Payback Times for the Hubei Province Department of Education Building (office building)*

Technique	Energy Savings (%)	Gross Payback Time (year)
Exterior insulation (5 cm.)	5.5	15.4
Clear double-pane windows	4.0	31.1
Exterior sun shades	3.2	20.6
Improved lighting	4.5	5.2
Improved electricity distribution	3.1	6.6
Improvements to active systems	6.3	6

Source: project team, group A.

Here, we can clearly see the distinction we mentioned earlier: envelope rehabilitation techniques are costly and have longer payback times – more than 15 years. Techniques that improve active systems and electricity management are much less expensive and, while generating energy savings of roughly the same magnitude, have much shorter payback times – 5 to 6 years. Payback times are even shorter when looking at very energy guzzling buildings.

Indeed, we can consider the difference between envelope improvements and systems improvements to be caused by the following elements:

- investment costs are very different. Investing in renovating lighting, for example, costs an average of 30 RMB per sq. m. whereas renovating glass surfaces can cost two to four times more depending on the proportion of windows to walls (a difference that can be seen immediately on the orders of magnitude for gross payback times).
- savings generated by improving the envelope are more or less consistent according to the type of building concerned: they vary based on the level of comfort required in the building (offices vs. hospitals, for example) and the output of production equipment, but have roughly the same order of magnitude.
- on the contrary, savings on active systems are proportional to building consumption. Therefore, the more energy a building consumes, the more effective investments in improving these systems are. It is important to keep in mind the fact that the order of magnitude for energy savings will vary according to the consumption of the building concerned.

These observations are generalities, and must not replace individual analysis of each case.

Once these different points have been noted, it is obvious that owners' first choices will naturally turn to "light" retrofitting, or only improvements in active systems and lighting. This is not a complete building retrofit, which should include both systems and envelope rehabilitations.

As we have seen, rehabilitating the envelope alone is not easy to justify from the economic standpoint. The notion of a combination of measures, a "package" adapted to a specific type of building, is what will make the overall investment economically viable. Thus, retrofitting the envelope can only be justified as part of a comprehensive retrofit involving equipment as well. In a way, the short payback time on systems retrofits and the long payback times on envelope retrofits can average themselves out if one invests in all measures.

Table 11 presents the package of measures determined for an office building (here, the Hubei Province Department of Education building).

Table 11 *Package of Retrofitting Techniques and Payback Times for the Hubei Province Department of Education Building (office building)*

Technique	Gross Payback Time (year)
Replacing lighting + control by light intensity sensor	3.7
Replacing pumps with variable output models	2.2
Interior insulation	12.1
Exterior sun shades	22.7
Combination	9.8

Source: project team, group A.

Combining investments that have short payback times with heavier investments makes it possible to generate combined savings that bring the total payback time to less than ten years. This was the criteria set by the working group for this research program. Indeed, usually, the maximum payback time considered by investors and banks is seven years. In the context of a pilot program, this number can be pushed to ten years, given the government support. Table 12 presents the economic data for this package.

Table 12 *Investment, Annual Financial Savings and Payback Time for the Hubei Province Department of Education Building (office building)*

Investment Cost	169 RMB per sq. m. of NFA
Annual Financial Savings	17.2 RMB per sq. m. per year
Gross Payback Time	9.8 years

Source: project team, group A.

3.5.2. *Determining suitable combinations of techniques*

Once these analyses have been run on several types of buildings, one can determine the lengths to which the thermal retrofitting can be "pushed" for the various categories of large public buildings. Table 13 presents the general techno-economic results for office buildings, hospitals and hotels.

Table 13 *General Techno-Economic Results by Type of Building (offices, hospitals and hotels) in Hubei Province*

The figures in blue are the most likely options to explore in greater detail in a feasibility study (from dark to light blue).

Offices	Systems	Systems + Sun Shades	Systems + Sun Shades + Double-Pane	Systems + Sun Shades + Exterior Insulation	Systems + Sun Shades + Double-Pane + Exterior Insulation
Gross Payback Time (year)	6	**8.3**	10.8	9.4	11.1
Investment Cost (RMB/sq. m. NFA)	100	152	203.9	191.9	243.8

Source: project team, group A.

Hotels

	Systems	Systems + Sun Shades	Systems + Sun Shades + Double-Pane	Systems + Sun Shades + Exterior Insulation	Systems + Sun Shades + Double-Pane + Exterior Insulation
Gross Payback Time (year)	3.3	3.6		**4.4**	
Investment Cost (RMB/sq. m. NFA)	125	142.8		**184**	

Hospitals

	Systems	Systems + Sun Shades	Systems + Sun Shades + Double-Pane	Systems + Sun Shades + Exterior Insulation	Systems + Sun Shades + Double-Pane + Exterior Insulation
Gross Payback Time (year)	4.1	4.9	5.6	5.5	**5.6**
Investment Cost (RMB/sq. m. NFA)	100	129.7	159.4	175	**204.7**

Source: project team, group A.

Table 13 shows the progression of feasibility according to building type: offices, which are among the buildings that consume the least energy, and then hotels and hospitals, which are among those that consume the most. By sorting according to the criteria of payback time, we can predict the following general feasibility results:

- *offices:* here, investments are the least profitable. Feasibility will probably lead to retrofits including systems and sun shades. Windows will be included, or not, on a case by case basis.

- *Hotels:* hotels generally already have double-pane windows for acoustic comfort. That option can therefore be ignored. As these buildings already guzzle energy, they tend to make system retrofits profitable, which lowers the overall payback time. Next, because of the level of comfort demanded, savings from envelope retrofits also have a tendency to be high. Feasibility is therefore positive for heavy retrofitting of luxury hotels including external insulation.
- *hospitals:* heavy retrofitting, like hotels. Also, not necessarily equipped with double-pane windows, which leaves this option open.

3.6. Typical retrofitting programs

The survey, audit and techno-economic calculation method was used to determine typical programs for each category of building. It is obvious that each project is unique and that, ultimately, a procedure elaborated on an case-by-case basis will need to be followed. However, a representative "menu" of retrofitting options for a category of buildings in a given climate and economic context is an important tool to advance on the issue of large-scale financing. It is in this spirit that these programs were defined; the three examples offered here illustrate the differences.

3.6.1. *Typical program for office buildings*

These are buildings for which retrofitting the envelope and systems can be justified, but for which economic feasibility is not as good as for other types of buildings. Insulating walls and roofs, replacing windows or applying solar film and sun shades, and optimizing natural lighting are strategies to be considered on a case-by-case basis. We have seen that office buildings represent less potential savings than public buildings such as hospitals, hotels and shopping centers. In addition, they often run on electricity.

The simulations show that improving the envelope is most effective through actions on windows (replacing them with double-pane windows) and the installation of outside sun shades. The best solution consists, of course, of also improving building insulation, but we have shown that this represents a different volume of investments and, if forced to choose an intermediary level, offices should focus on glazed surfaces. Differentiating between tall and medium-height buildings is recommended. The former make retrofitting difficult when it comes to exterior insulation. In addition, the decorative elements of the external envelope are often high-end and expensive to replace. Replacing windows and insulating from the inside seem more practical options for these buildings. The latter are more suited to the application of exterior insulation.

For systems, the aim is to lower the load, in particular air conditioning. A large proportion of this load is caused by fresh air and sunlight because occupation density is low. Optimizing fresh air output can reduce the load.

The aim is also to increase the yield in hot and cold production (at least through maintenance of ducts, and using variable frequency compressors), lowering the consumption of pumps by replacing them with variable frequency pumps, and possibly installing terminal regulation. Setting up a building management system (BMS) and dynamic energy management is relevant.

3.6.2. *Typical program for shopping centers*

Envelope retrofitting is less justified for these buildings. HVAC system performance is the key point. Losses through the envelope are responsible for less than 10% of the energy bill. Inside gains are very important. These buildings have large surface areas, few windows, and considerable circulation and lighting. The HVAC system improvement strategy consists of lowering the load of fresh air regulation, increasing the coefficient of performance (COP) of energy production, installing a BMS, and examining natural sources of cooling. For instance, fans and pumps consume a lot, and it is important to reduce flows by installing variable frequency pumps.

3.6.3. *Typical program for luxury hotels*

The envelope and systems are subject to retrofitting. The usage characteristics are the variation in the supply of fresh air based on occupancy; air conditioning and hot water must be available at all times. Heat production demands are therefore higher than in offices and shopping centers. Since hotels operate with centralized air conditioning and heating, partial load control, maintenance of existing systems, and use of efficient equipment are the most logical measures. A strategy of recovering heat from the cold unit condenser or a heat pump during the summer is recommended for hot water.

For the envelope, insulation, natural lighting and replacing windows are effective measures. Unlike office buildings, hotels are in a category of buildings that operate more often with oil or even coal boilers. This implies low production yields, and the share in consumption from HVAC equipment, especially heating, is often higher (than in office and administrative buildings). Thus, while costs are prohibitive for total envelope improvement (insulation + double-pane windows + external sun shades), the simulations show that insulation and applying solar film to existing windows make up the most efficient intermediary improvement level.

3.7. Impacts of retrofitting

Once typical retrofitting programs have been determined, with their estimated investment costs, energy savings and financial savings, it is possible to estimate the challenge of large-scale thermal retrofitting of public buildings.

The challenges were extrapolated on three scales: *(i)* the city of Wuhan, *(ii)* Hubei Province, and *(iii)* the Yangtze basin (combining four similar provinces for this purpose).

Extrapolations were also done based on investment level, which provides a scale on which to situate the project so that the contracting authorities can then decide how far to go between light retrofitting and heavy retrofitting.

In this way, we obtained a graduated scale from systems retrofitting alone to an intermediary level in which the envelope is partially improved (as with office buildings, for instance) to complete retrofitting of systems and the envelope.

3.7.1. *Citywide extrapolation in Wuhan*

Within the city of Wuhan's stock of public buildings and administrative buildings, the surface area concerned by thermal retrofitting measures is approximately 37,400,000 sq. m. This city has a population of 8.28 million people.

System improvements only

Investment Cost: 4.1 billion RMB

Annual savings: 0.76 billion RMB

Primary energy savings: 0.3 Mtce/year, or 13% of the total

Unitary investment cost by unit of primary energy saved: 13.70 RMB/kgce saved

Reduction in CO_2 emissions: 0.8 MT CO_2/year

Unitary investment cost per ton of CO_2 avoided: 5,125 RMB/t CO_2 avoided

Systems and "mid-level" envelope improvements

Investment Cost: 8.6 billion RMB

Annual Savings: 1.1 billion RMB

Primary Energy Savings: 0.42 Mtce/year, or 19% of the total

Unitary investment cost by unit of primary energy saved: 20.50 RMB/kgce saved

Reduction in CO_2 emissions: 1.1 MT CO_2/year

Unitary investment cost per ton of CO_2 avoided: 7,818 RMB/t CO_2 avoided

Systems and "high-level" envelope improvements

Investment cost: 11.2 billion RMB

Annual savings: 1.4 billion RMB

Primary energy savings: 0.53 Mtce/year, or 24% of the total

Unitary investment cost by unit of primary energy saved: 21 RMB/kgce saved

Reduction in CO_2 emissions: 1.4 MT CO_2/year

Unitary investment cost per ton of CO_2 avoided: 8,000 RMB/t CO_2 avoided

3.7.2. *Extrapolation to Hubei Province*

We can use these results from the study in Wuhan to extrapolate orders of magnitude for energy savings and investments in Hubei Province. First, we can assume that the climate in Wuhan is representative of the climate throughout the province. Thus, to extrapolate city results to the province, we need to know building surface statistics. The value that is of interest is the surface area of large public and administrative buildings.

The statistics for Hubei Province are as follows:

- surface area of public buildings: 263 million sq. m.;
- surface area of large public buildings and administrative buildings: 131.5 million sq. m.; [11] and
- population: 60.7 million people.

System improvements only

Investment cost: 14.5 billion RMB

Annual savings: 2.7 billion RMB

Primary energy savings: 1.1 Mtce/year, or 13% of the total

Unitary investment cost by unit of primary energy saved: 13.70 RMB/kgce saved

Reduction in CO_2 emissions: 2.9 MT CO_2/year

Unitary investment cost per ton of CO_2 avoided: 5,125 RMB/t CO_2 avoided

[11] We assume that, as in Wuhan, the surface area of large public buildings and administrative buildings accounts for half the surface area of all public buildings.

Systems and "mid-level" envelope improvements

Investment cost: 30.2 billion RMB

Annual savings: 3.9 billion RMB

Primary energy savings: 1.47 Mtce/year, or 19% of the total

Unitary investment cost by unit of primary energy saved: 20.50 RMB/kgce saved

Reduction in CO_2 emissions: 3.8 MT CO_2/year

Unitary investment cost per ton of CO_2 avoided: 7,818 RMB/t CO_2 avoided

Systems and "high-level" envelope improvements

Investment cost: 39.5 billion RMB

Annual savings: 4.9 billion RMB

Primary energy savings: 1.9 Mtce/year, or 24% of the total

Unitary investment cost by unit of primary energy saved: 21 RMB/kgce saved

Reduction in CO_2 emissions: 4.9 MT CO_2/year

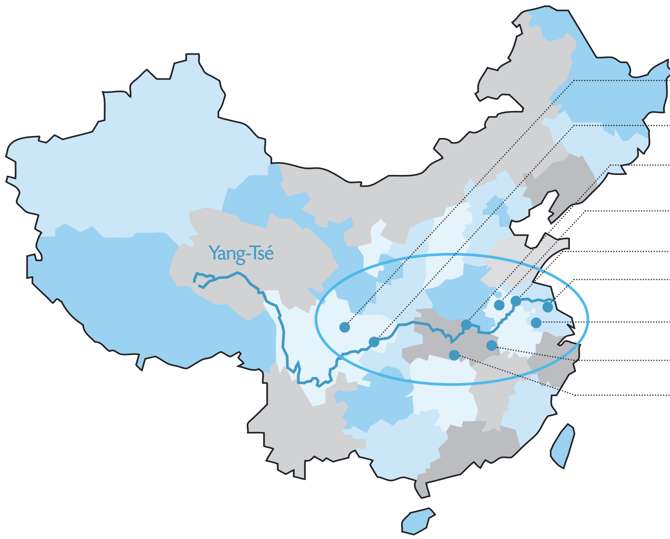
Unitary investment cost per ton of CO_2 avoided: 8,000 RMB/t CO_2 avoided

3.7.3. *Extrapolation to the Yangtze River basin*

In the Yangtze basin, we can identify a certain number of provinces that could take advantage of the estimates for Wuhan and Hubei. The crucial issues, to justify extrapolating results, deal with the similarity of the climate and surface area statistics. We attempted to verify these two points in nine provinces along the Yangtze River, represented by the climate data from nine cities (the provincial capitals):

- Shanghai (city of Shanghai);
- Hunan (city of Changsha);
- Hubei (city of Wuhan);
- Jiangxi (city of Nanchang);
- Anhui (city of Hefei);
- Chongqing Shi (city of Chongqing);
- Sichuan (city of Chengdu);
- Jiangsu (city of Nanjing);
- Zhejiang (city of Hangzhou).

Map 2 *Location of Cities and Provinces along the Yangtze River*



Source: Map of China, based on the State Bureau of Surveying and Mapping's internet map.

Conclusions on climate similarity

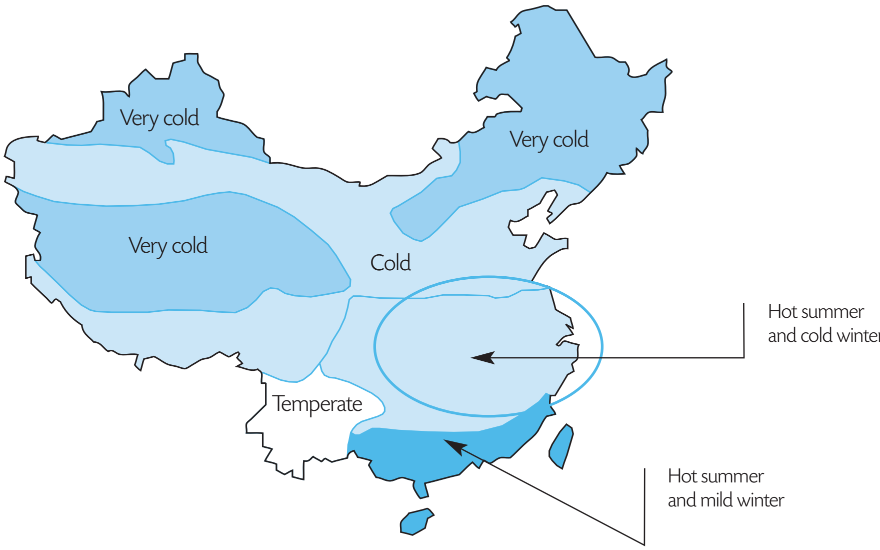
We can say that the cities of Shanghai, Nanjing, Hangzhou, Hefei, Nanchang, Wuhan and Changsha are fairly similar when it comes to the main weather parameters. Sunshine is a special case, and the data vary too much from one source to another to draw firm conclusions.

The cities of Chengdu and Chongqing are somewhat outside this climate "bundle" because of their more western geographic position, near the border between the "hot summer and cold winter" zone and the "cold winter" zone.

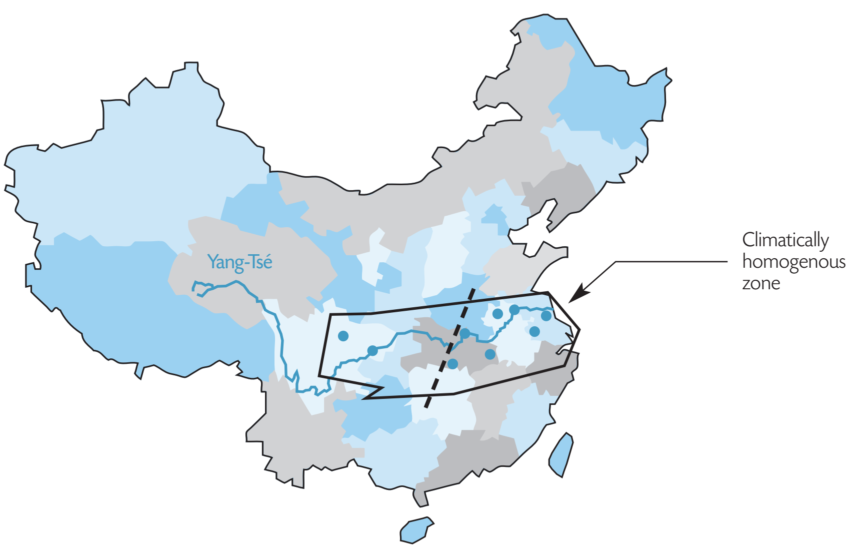
This distinction therefore primarily concerns the region encompassing Sichuan and Chongqing Provinces. As these two provinces span two climate zones, it is prudent to exclude them.

We can therefore assume that the climate along the Yangtze River is fairly homogenous, based on a comparison of several parameters. The energy analyses in Wuhan can therefore serve as an initial basis to extrapolate the results to the provinces along the Yangtze, with the exception of Sichuan where the results will need to be recalculated.

Map 3 *Homogenous climate zones*



Source: Lawrence Berkeley National Laboratory.



Source: Map of China, based on the State Bureau of Surveying and Mapping's internet map.

Conclusions on built-up surface statistics

Marginal behaviour can be observed in the provinces of Jiangsu and Zhejiang, which build much more than the others. They are located in the eastern part of the river basin, around Shanghai. The statistics show that urban development there is fairly different from in other provinces; industry notably occupies more space. The same tendency can be seen in Shanghai. All of this coastal region showed surface area statistics that differ from the more inland provinces. For these reasons, we believe that the work in Wuhan must be extrapolated to regions where the construction sector is homogenous.

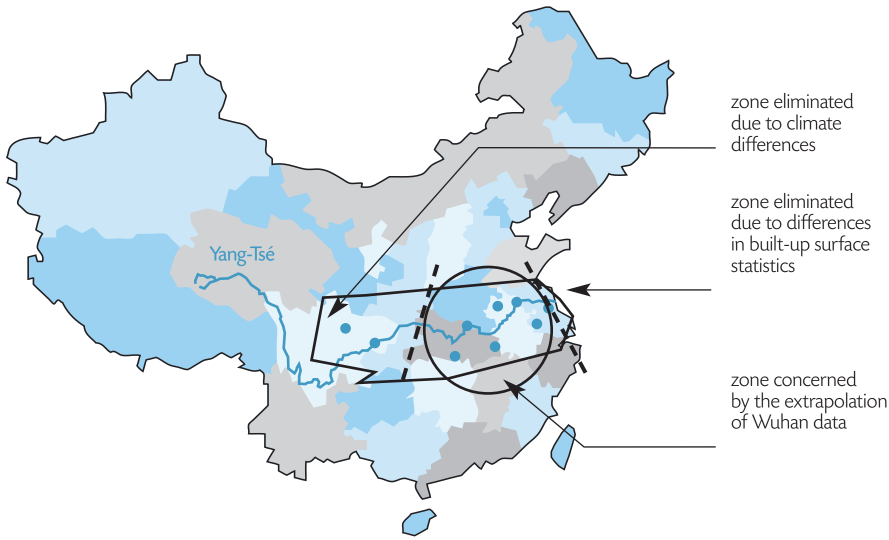
Based on built-up and total surface area statistics for Wuhan, Hubei and these four provinces, we obtain the following numbers:

- total urban built area: 2.56 billion sq. m.;
- built area devoted to urban housing: 1.67 billion sq. m.;
- built area of public buildings: 890 million sq. m.;
- population of the four provinces: approximately 235 million people.

We maintain the Wuhan distribution in which our sample of public buildings (large public buildings and administrative buildings) accounts for half of the public building stock, or approximately 445 million sq. m.

Map 4 indicates the zone in which we can theoretically extrapolate the results obtained in Wuhan.

Map 4 *Map of the various cities and provinces along the Yangtze*



Source: Map of China, based on the State Bureau of Surveying and Mapping's internet map.

On the scale of the Yangtze basin, the challenge therefore focuses on a surface area of 445 million sq. m. of public buildings in a homogenous climate zone.

System improvements only

Investment cost: 49 billion RMB

Annual savings: 9 billion RMB

Primary energy savings: 3.6 Mtce/year, or 13% of the total

Unitary investment cost by unit of primary energy saved: 13.70 RMB/kgce saved

Reduction in CO_2 emissions: 9.5 MT CO_2/year

Unitary investment cost per ton of CO_2 avoided: 5,125 RMB/t CO_2 avoided

Systems and "mid-level" envelope improvements

Investment cost: 102 billion RMB

Annual savings: 13.2 billion RMB

Primary energy savings: 5 Mtce/year, or 19% of the total

Unitary investment cost by unit of primary energy saved: 20.50 RMB/kgce saved

Reduction in CO_2 emissions: 13.1 MT CO_2/year

Unitary investment cost per ton of CO_2 avoided: 7,818 RMB/t CO_2 avoided

Systems and "high-level" envelope improvements:

Investment cost: 134 billion RMB

Annual savings: 16.7 billion RMB

Primary energy savings: 6.3 Mtce/year, or 24% of the total

Unitary investment cost by unit of primary energy saved: 21 RMB/kgce saved

Reduction in CO_2 emissions: 16.4 MT CO_2/year

Unitary investment cost per ton of CO_2 avoided: 8,000 RMB/t CO_2 avoided

Part Four

4. Institutions and partners in the decision-making, organizational and financing process

Preamble

Thermal retrofitting of buildings crystallizes, at of course still distinct levels, the interests of the government authorities and economic operators. Addressing potential energy savings naturally triggers a series of converging benefits for society:

- source of new growth, and a bridging activity for the construction sector during slow periods in the real estate development sector;
- vector to improve the country's energy security, by lowering the building sector's dependency on imported primary energy;
- improved building use conditions and comfort; and
- a reduction in local pollution and impacts on the overall environment.

This shared vision of the interest to be found in acting on this property has not yet come with an independent commitment to act from the parties involved and, in particular those who manage and use the property. The situation in China is, from this point of view, very similar to the situation in France or other OECD countries.

Certain externalities (cost of energy for consumers in particular, greater profitability of investments in other sectors including real estate development) and certain distortions and/or breaks in the transmission of market signals (dichotomy of interests between building owners and building occupants/renters notably) still all too often create a situation in which the person investing in energy efficiency cannot draw all the potential associated benefits. Despite these difficulties, renovating the existing building stock is one of the priorities (and drivers) of China's energy control policy, as illustrated by the formula used to describe the national three-part objective:

- *developing renewable energies in three stages:* 61 pilot projects financed by the central government that will lead to the designation of cities or provinces for larger-scale experimentation prior to roll out throughout China;
- *construction of "green buildings"* that comply with specific standards, following research-and-development work on the materials needed to create ecological buildings in the broad sense (not merely energy efficient buildings); and
- *retrofitting the existing building stock,* with a plan covering 150 million sq. m., 40 million of which were retrofit in 2008, 60 in 2009 and probably another 60 in 2010.

The efforts undertaken between 2000 and 2010, strongly supported by the central government through grants and dedicated lines of financing, is slated to continue: the 12th five-year plan, which began in 2011, has the objective of renovating – in the housing sector alone – 300 million sq. m. (approximately 6 million homes). Faced with a challenge of this magnitude, the issue of financing is a decisive factor in success, and the government is fully aware that the incentive systems, based on grants from the national budget, cannot be maintained indefinitely.

In this chapter, we start with a presentation of the organizations and institutional dynamics on which provincial and local initiatives in the field of energy conservation lean, and we illustrate the state of current practices in regard to financing retrofitting investments and their limits. We then present a review of the level of interest and commitment among the public and private actors concerned by retrofitting programs, highlighting the sticking points identified in the framework of the consultations and discussions led by the Sino-French research team.

The reform process underway on the national level since 1988 is accompanied by decentralization and responsibility transfer. Today, 65% of public spending is covered by local, provincial and municipal authorities.

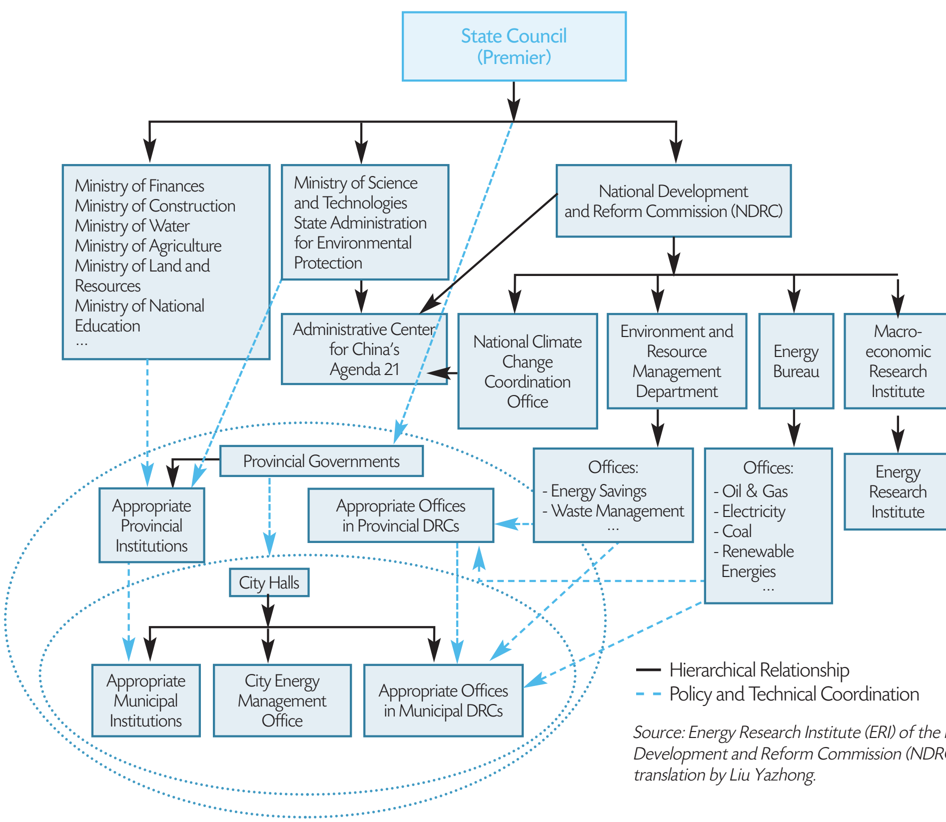
In regard to energy efficiency and the promotion of renewable energies, the actions by the central authorities concentrate on the macroeconomic level by deploying legislative tools, standards, regulations, and so on (construction standards, thermal regulations, taxation, subsidies, dedicated lines of financing, etc.).

4.1. Overall structure of energy efficiency in China

Following the last institutional reform in 2003, the National Development and Reform Commission plays a true role as national orchestral conductor for energy control actions, renewable energy promotion, and the development of the environmental industry. It has annexed the offices responsible for these areas that used to be part of the former State Economic and Trade Commission.

Schema 9 offers (as much as possible) a description of the new decision-making structure when it comes to the environment, energy efficiency and renewable energies (this is a simplified schema, the decision-making structure is more complicated in reality).

Schema 9 *Organizational Chart of China's Energy Efficiency Structure*



Source: Energy Research Institute (ERI) of the National Development and Reform Commission (NDRC); translation by Liu Yazhong.

To facilitate understanding, the national level in China is now roughly the equivalent of the European Commission, and the provincial level in China is the rough equivalent of the EU member-countries. There is, however, one major difference: administrative exchanges and supervision between the two levels in China are much stronger than those between the European Commission and the member countries.

The municipal level in China is the equivalent of France's regions, but city halls in China have more autonomy than France's regional councils.

In this way, the central institutions in China play a more coordinating role, and the provincial and municipal levels play more operational roles.

4.1.1. *On national level*

The National Development and Reform Commission (NDRC) is in charge of coordinating inter-sector and inter-region development. When it comes to energy efficiency, renewable energy promotion and the environment, four departments and institutions are involved under the NDRC. They are presented below.

Energy Research Institute

Reporting directly to the Macroeconomic Research Institute, the ERI is in charge of providing "politico-technical" assistance to Chinese institutions for the elaboration of their sectoral policies and the organization of and participation in international negotiations. Its research responsibilities focus on the following fields:

- the national energy savings development strategy;
- the energy efficiency strategy and actions to undertake in the various sectors in this regard;
- the impacts of energy production and consumption on climate change;
- the sectoral renewable energy promotion policy;
- contributions to drafting the country's energy policy; and
- the development of computer models: action assessment model for greenhouse gas emission reduction – SGM [12] (China), and the Integrated Policy Assessment model for China (IPAC) which assesses the impacts of policies on economic and social development.

[12] This is a macroeconomic model. Like other models, it enables the simulation of inter-sectoral interactions and the propagation of the effects of emission reduction policies throughout the economy. These models provide an evaluation of the macroeconomic cost of reduction policies in the form of variations in GDP or costs in well-being, once all the effects of the system in the economy have been taken into account. The SGM model is mainly devoted to energy. In France, the simulation models generally used are GEMINI-E3 and LINKAGE-ENV (the successor to GREEN at the OECD). Worldwide, the best known models in this category include the EPPA, Worldscan, SGM, WIAGEM and AMIGA.

Energy Bureau

In charge of coordinating the development of energy production and supply throughout China, this office organizes and participates in the elaboration of the energy production policy (coal, oil, natural gas, electricity and heat). All new energy production projects whose installed power or investments exceed the local government's approval threshold [13] must be approved by the appropriate offices in this Bureau. It is also in charge of implementing the policy on the promotion of renewable, wind, solar, and mini and micro hydraulic energies. Energy efficiency action plans in energy production companies are also under its remit.

Environment and Resource Management Department [14]

This department is responsible for elaborating and applying national energy efficiency, waste management, and environmental industry development policies.

When it comes to energy efficiency, until 2006, it limited its activity to the industrial sector with an annual intervention budget of 10 to 20 billion RMB/year. These funds were mobilized in the form of soft loans for industrial innovation projects and financing energy saving equipment (the list of eligible equipment was written up every year by the department).

Starting with the 11th five-year plan (2006-2010), this department included energy efficiency in buildings in its action plans. It will finance, through direct grants and soft loans, pilot projects renovating public buildings and housing, as part of the national goal of cutting energy intensity by 20% by the end of the 11th plan.

Office of National Climate Change Coordination

Chinese coordinator of application of the Rio Convention and Kyoto Protocol, this office is part of the Regional Economy Department. It is in charge of elaborating – and notably coordinating application of – regional economic and social development policy while integrating the implementation of clean development mechanisms in regional development.

[13] The threshold varies according to province and city, and we cannot cite all of them in this document.

[14] This institution is known in the energy efficiency and environmental field in France under its former name: the Bureau of Energy Savings and Rational Resource Use (BESRRU).

4.1.2. *In the provinces*

In each province, the governors and their assistants are elected during the plenary session of the provincial assembly, which is often chaired by the Secretary of the Chinese Communist Party provincial committee. All the administrative institutions, offices and commissions report directly to the provincial government and directors are nominated, in principle, by the governor and approved by the assembly. The administrative structure is almost exactly the same in the provinces as on the national level. There is therefore a provincial institution equivalent to each national ministry or commission, however the connection between the institutions on the two levels is more technical and coordinating. Of course, there are subjects [15] and projects [16] that must be handled or approved by the central institutions.

Like the NDRC, the provincial Development and Reform Commission (DRC) plays the role of coordinator of economic and social development in the province. For historical reasons, the provincial institutions are more executive and more pragmatic than national institutions. The resources devoted to research and studies there are therefore more limited. For instance, there is no provincial equivalent of the ERI. Nevertheless, they work extensively with public laboratories and research centers, universities and academics. For instance, there is always a science and techniques committee composed of the major local experts and specialists in the fields of construction materials, architecture, civil engineering, construction, thermal issues, etc. within the provincial or municipal construction departments.

Local offices, whether provincial or municipal, have more operational missions than those at the central level.

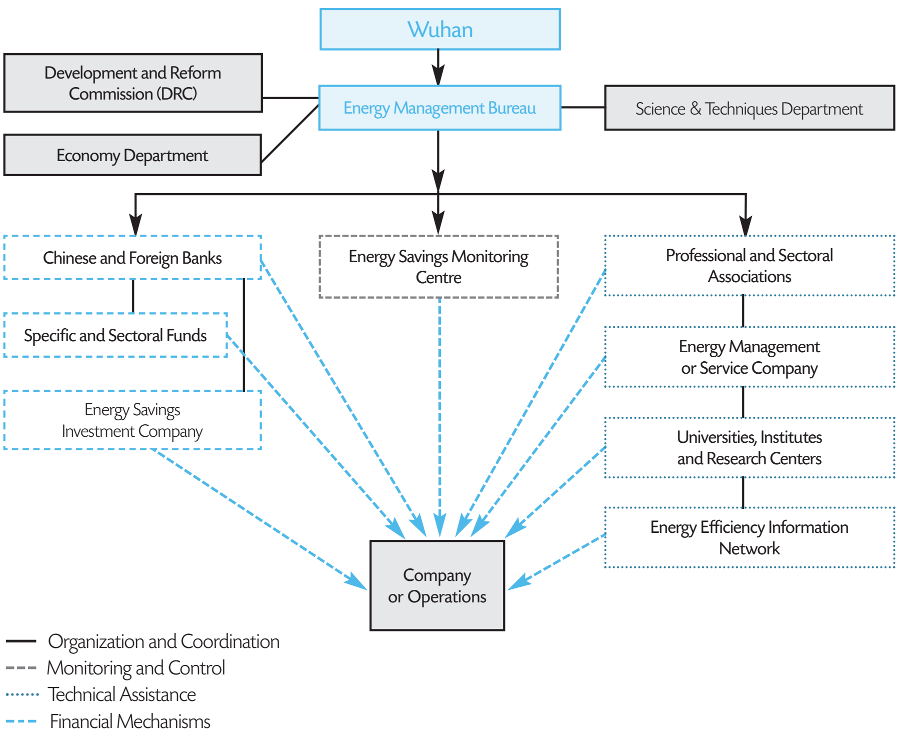
[15] Diplomatic relations, national defense, etc.

[16] Large infrastructure projects or projects for which the necessary investments exceed the threshold set for approval by the appropriate provincial authorities

4.1.3. *On the municipal level*

The structure and operation of municipal administrations are the same as on the provincial level. Concrete operations are conducted at this level.

Schema 10 *Intervention Structure for the Execution of Energy Efficiency Projects in Wuhan*

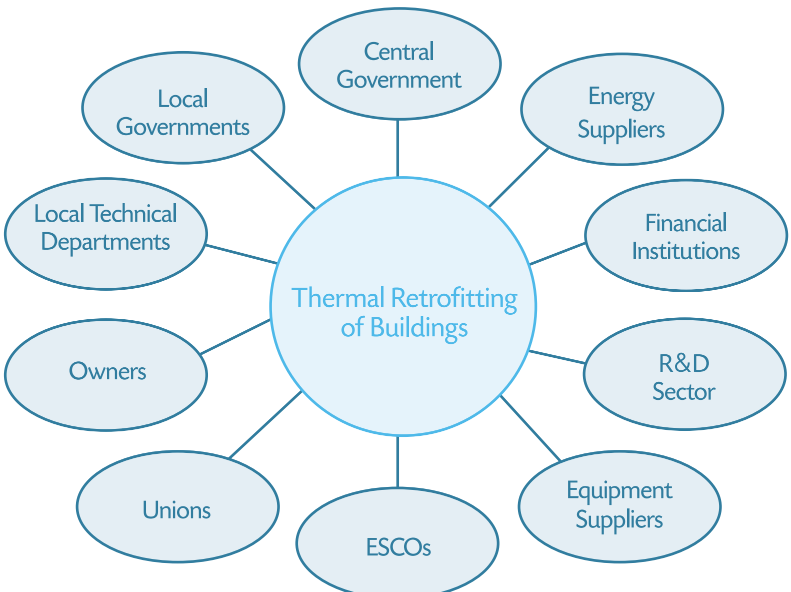


Source: City of Wuhan Energy Management Bureau; translation by Yazhong Liu.

4.2. Interests and barriers to the development of investing in the thermal retrofitting of buildings: interplay among actors

4.2.1. *Actors involved in the energy efficiency retrofitting of buildings*

Schema 11 *Retrofitting Actors*



Source: ICE.

We have seen that the central government and provincial and local institutions have structures and resources devoted to promoting and supporting energy efficiency. We have also shown, in part two of this document, how these institutions were involved, with the support of the AFD and its consultants, in formalizing the energy and greenhouse gas emission mitigation challenges involved in large-scale building retrofitting programs. Alongside these institutional actors, economic actors (promoters, managers, service companies, financial institutions, etc.) have also expressed a desire to better understand the economic interest of such programs and the conditions under which they could participate in them.

However, it appears that, for reasons of frequently different natures, most of the actors felt that their willingness to get involved was limited by institutional, economic or financial constraints. The Sino-French research team conducted interviews with the various stakeholders to evaluate their respective positions and identify possible recommendations and future financial structures. We present the roles and positions of each of these actors below.

4.2.2. *The central government*

The institutions representing the national interest send an extremely positive message in regard to the process undertaken by Hubei Province. It fits directly in line with the national energy efficiency strategy and targets a sector with strong economic and social stakes – not to mention environmental and "reputation" stakes – in this way shoring up China's credibility in the international climate talks. The motivation to see the development of thermal retrofitting programs for buildings is therefore very high. At the same time, the central government and its dedicated structures do not have sufficient resources to support all provincial initiatives by allocating grants, as had been the case in 2000 and 2010 for the priority retrofitting programs conducted in the northern provinces of the country (see Box 2).

Box 2 *The Energy Retrofitting Framework for Existing Buildings in Northern China*

Retrofitting program content and actors

On the technical level, the retrofitting in Northern China took place in three stages: *(i)* renovation of thermal metering installations, *(ii)* renovation of heating networks, and *(iii)* envelope retrofits (walls, roofs, windows and doors). Public actors (the central government, local governments, i.e. regions and municipalities) were involved along with neighbourhood committees.

Each actor had a specific role to play in the process:

- *The central government* (*i.e.* the Ministry of Housing and Urban and Rural Development, and the Ministry of Finances) set the overall retrofitting target (*i.e.* the surface area of housing to renovate) and the distribution of this target among the fifteen northern provinces; set the renovation standards and operating modes; and determined the human resources to mobilize (training manual, consultancy firms, executing firms, monitors, etc.). It was in charge of evaluating and validating the work.
- *The regional and local governments* set up the financing to accompany the retrofits, conducted surveys to measure energy consumption, and could issue more demanding renovation standards than those issued by the central government.

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- *The neighbourhood committees* organized the work: door-to-door outreach to inhabitants to raise households' awareness of energy efficiency and get them to join the program; calls for tender for the execution of the work.

The actors involved in program implementation were private actors: property owners, inhabitants, heating supply companies and ESCOs (that have played a minimal role for the time being). They were involved in the decision-making, financing and execution phases of the various stages of elaborating and executing the work.

Financing modes

Various financing modes existed according to the status of the sponsor in charge of the retrofitting operation. As a general rule, the central government subsidized renovation operations in the north, up to an average of 50 RMB/sq. m. or roughly 25% of the cost of the retrofits. Most of the time, this first level of subsidization and incentive was supplemented by a matching grant allocated by the province and municipality. The owner was usually responsible for covering the rest of the cost of the work. When property developers undertook retrofitting operations, they financed them by increasing the inhabited surface through two processes: adding floors or including balconies in a larger structure (gaining 20 sq. m. per housing unit on average). In some cases, under pressure from the government, heat distribution companies (some of which public) invested; in other cases, construction companies did the work using their own funds (recovering the investment from the savings realized).

Property management companies

In Shandong Province, the renovation of the State University (affecting heating networks and energy meters) was done with an investment of 5 million RMB. Savings of 40% were generated compared to the initial situation. The property development company collects the heating fees. These fees remained the same after the retrofit for a certain period of time to allow the company to recoup its investment. Once the investment has been amortized, heating fees drop. This is a fairly simple model that is tending to spread in China.

The simplest system is the one implemented by large companies (oil companies, automobile manufacturers, banks, etc.) that own buildings (and sometimes even heating networks). In addition to owning the buildings (employee housing and offices) and heating networks, they also have the financial clout to invest themselves in renovating the property or support the energy efficiency investments of occupants in the renovation of the property. An automobile manufacturer, for example, gave the families it housed an incentive to renovate their housing by offering bonuses to the first households to participate.

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Ultimately, the inhabitants are the ones that take the initiative to renovate, as was the case in the city of Chenyang. Some inhabitants lived in under-heated, damp (mold), noisy housing; they therefore organized to contact construction companies and organize financing and execution of thermal upgrading of the housing.

Special case

In the poor province of Ninxia, the municipality and the region did not have funds so the State subsidized 25%, the heating company provided 20%, the inhabitants 15%, and the construction company the remaining 40%.

A recent study comparing the renovation modes (individual or collective) shows that individual retrofits have the advantage of being one third less expensive: this is because they only deal with walls (insulation) and windows. These individual renovations are initiated by occupants to solve problems of moisture or noise and to improve thermal comfort (16°C in the winter).

While collective renovations are more expensive, after the work, the buildings consume less energy than under individual retrofits. These renovations are partially subsidized by the State; an agency expedites execution (with calls for tender) and monitors the work.

Lessons and difficulties encountered

Even though thermal retrofitting programs and experiences are a recent approach in China, some lessons can be learnt:

- intervention by the central government is primordial to the success of retrofitting programs when it comes to the definition and steering of the program, definition of targets and standards, and financial support *via* grants (without the financing in the amount of 50 RMB/sq. m. from the central government, nothing would have been done on the 150 million sq. m.).
- next, there are the issues of funding sustainability: while the association of private funds and market mechanisms seems obvious, how can this be accomplished? (There are no government banks in China, only commercial banks.) Awarness on these issues should then be increase at policy decision makers level. Policy and programs assessment policy must also be set up at every decision-making level. (There is not enough assessment: only 20% of programs are subject to evaluation.)
- there are also questions on the coordination of numerous actors and the responsibilities of local authorities. A scientific, supervised approach to retrofitting must be adopted (legal procedures, audits, surveys, calls for tender, results measurements *via* meters, reports). Reflection is also needed on the operating modes suited to the provinces, given the size of the country. Finally, it is important the neighbourhood committees be the first relay of government policy to convince inhabitants.

4.2.3. *The province and the city*

The attention to and interest in energy efficiency development programs in the building sector among the provincial and local authorities obviously relays the priorities set nationally (materialized by the goal of rapidly reducing the magnitude of energy intensity: a 20% cut over the 11th Plan's execution period). It would, however, be inaccurate to limit the provincial and local interest to this argument alone.

Indeed, the reasons why Hubei Province and the City of Wuhan were interested in improving energy efficiency were also local in nature: the rising energy bills on their own premises and the premises of the organizations and offices that they fund through their budgets were the main source of motivation. In addition to this, there is the local governments' responsibility for ensuring and guaranteeing the security and quality of the energy supply.

Yet, when energy demand (and in particular demand for electricity) is growing rapidly, as it does with the economic development of the province, imbalances can emerge between supply and demand. They come with power rationing and sometimes supply shortages for the primary energy (mainly coal) needed to produce electricity. Energy efficiency therefore seems to be a crucial factor in better management of existing capacities and optimized planning of capacity building investments.

These favourable factors are, however, offset by the political trade-offs imposed by the local context. At the top of the list of these trade-offs, negatively impacting the feasibility of priority commitment of local government funds, is the inescapable hierarchy of budget priorities. With budgets remaining the same, government authorities finance in priority those investments that are urgent in the short term (urban infrastructures, economic development, social priorities). These priorities, which manifest the requirement of economic growth, naturally have a conflict of interests with the goals in the energy efficiency and environmental policy. Among other things, policy decisions are part of the local term of office cycle (5-year terms of office) that mandates concrete results that can be measured against the yardstick of economic and financial performance indicators. Yet, one is forced to admit that the profitability of energy efficiency investments in existing buildings comes, for example, much later than real estate development investments. What is more, the visibility and promotional dimension of energy savings projects are much lower than they are with other projects under policy jurisdiction and decision-making, and this category of projects cannot be maintained lastingly as priorities for political action.

Finally, when provincial and local institutions undertake an ambitious retrofitting program with determination (as was the case for the research program), inter-department and inter-office communication, exchange and cooperation capacities are key factors in success. Yet, the culture and experience of this crosscutting aspect (between technical departments and offices, and departments and offices in charge of property, economics or finances) are still in their infancy; they therefore lengthen consultation and decision-making processes and slow the updating of synergies in resources.

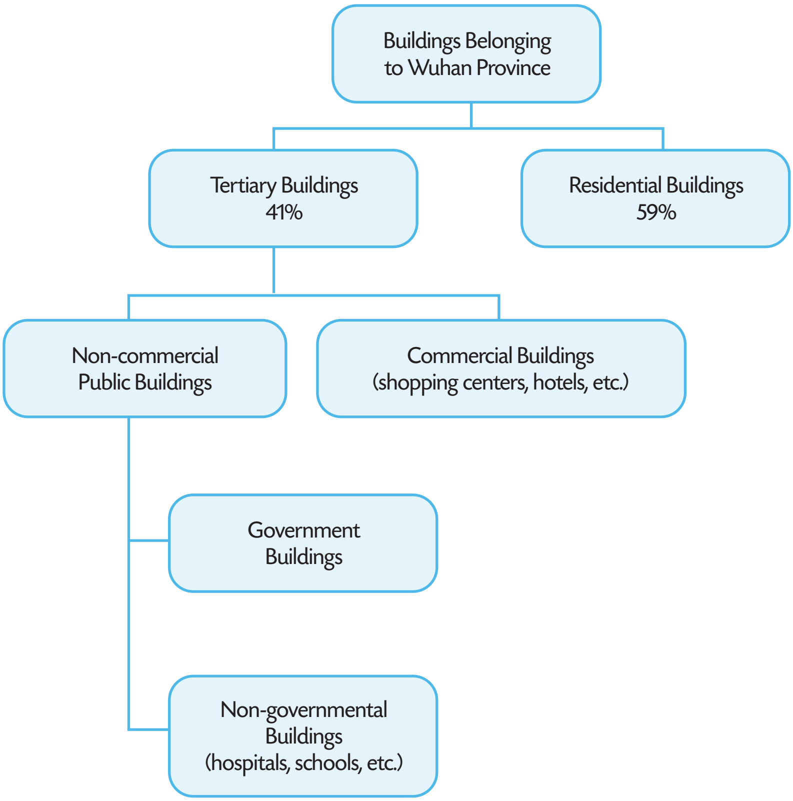
4.2.4. *Building owners*

A very broad typology of buildings (offices, educational facilities, hospitals, stores and shopping centers, sociocultural facilities, etc.) covers a diversity of ownership and occupation statuses for buildings that makes the decision-making process and energy efficiency investment implementation conditions more complex. For the portion of property with a public service status, the economic feasibility of a retrofitting project is, among other things, complex because of the fact that the cost of the energy bill can often be split between the owner, the occupant and the local or provincial institution's budget.

In this way, we differentiate between:

- public buildings whose operating expenses (including the energy bill) are covered by the public budget (buildings housing city or province administrative offices);
- service buildings whose operating expenses (including the energy bill) are covered by the public budget (hospitals, schools, etc.); and
- buildings whose expenses are covered directly by the occupant(s), without government support.

Schema 12 *Structure of the Building Stock in the Wuhan Urban Area*



Source: project team, group C.

Ownership status comes in at least four configurations:

- single government owner;
- single private owner;
- single or multiple private owner;
- multiple government owner.

Consequently, the interest of investing to improve the thermal performance of buildings depends on three motivations (that may or may not be present simultaneously):

- lowering the energy bill;
- improving the building's comfort standard and level;
- applying the insistent recommendations from the central government to act to improve the energy efficiency of the economy.

This interest is, however, mitigated by a certain number of non-technical barriers:

- heavy thermal retrofitting (envelope and systems) requires large sums to invest, and therefore competes with other investment needs (in particular with productive investments). In addition, these energy efficiency investments have much less attractive payback profiles than other investments.
- the decision-making process involves many actors with different motivations, reflecting distinct opportunity costs.

4.2.5. *Property management companies*

As new operators in the Chinese real estate market, management companies provide a range of services necessary for good building use (safety, cleaning, heating, air conditioning, green spaces, etc.) For these operators, contractually bound as to the quality of energy services in the buildings they manage, improving energy performance is a very interesting line of development. Indeed, low consumption can generate financial margins. This category of actors is therefore strongly motivated to invest in improving building energy performance. Nevertheless, still newcomers in the Chinese market, they lack references and credibility to sway owners' decisions to enter into contractual schemes that make it possible to improve building energy efficiency.

4.2.6. *Energy service companies (ESCOs)*

An ESCO is a company that invests in an energy efficiency project in the place of the owner ("third-party payer" principle), has the work done under its responsibility, and is paid (for the investment and services) by the energy savings realized. This formula is spreading rapidly in some European countries (Germany, Austria, Spain, and countries in Eastern Europe). It is used above all in the tertiary sector and, in preference, for grouped projects so as to attain sufficient investment size. The tricky part of this financing scheme is establishing the contract that connects the ESCO to its "client" insomuch as the two parties must agree on a protocol by which to determine baseline consumption before the renovations, and the conditions for monitoring the expected performance of the energy efficiency investments after the work. This information is what is used to determine the share of the savings on the energy bill that goes to the ESCO and, as a result, the length of time after which the initial investments by the ESCO will have been paid off. At this time, the ESCO's client will have all the energy savings and a thermally renovated building.

Emerging at the start of the 2000s on the Chinese market, energy service companies (ESCOs, also called energy service enterprises or ESEs) have grown rapidly in number – the China Energy Management Company Association (EMCA) has more than 300 members. They are still fairly small in size, although a few ESCOs have developed energy performance contract portfolios of several tens of millions of euros (in early 2007, there were 1,426 such contracts developed by these structures, according to the EMCA, for total investments in the amount of 550 million US dollars). These companies are growing in an extremely conducive economic and institutional context (strong economic growth on the environmental market, and institutional support for the development of economic activities that improve energy efficiency and lower greenhouse gas emissions). For these operators, the prospect of large-scale retrofitting programs is a strongly motivating factor to continue to develop this sector and to imagine legal-financial systems that suit the needs of the contracting authorities to do so.

ESCO activities rely on a simple mechanism: financing energy efficient investment costs with the energy savings realized by these investments. The ESCO covers the investment costs and/or provides guaranteed energy savings that allow the contracting authority to structure financing of its operation safely.

Implementation of this mechanism does however require the existence of certain conditions that are not necessarily all present in the Chinese market:

- The price of energy billed to the consumers must be at an acceptable level so that the financial savings from the operations are sufficient to allow the investment costs to be recovered and generate a profit for the ESCOs.
- ESCOs must have the financial standing to be credible in the eyes of potential clients (and notably be able to take on contractual obligations as to energy performance in regard to recommended energy savings), and in the eyes of the banking establishments that will have to provide the loans needed to finance the investments when they are not financed directly by the ESCOs themselves.

- ESCOs must be able to find on the market bank loans with interest rates and terms suitable to the financial performances of the projects they fund (and in particular have access to long-term finance that may extend beyond ten years to take into account projects with long payback times, which is generally the case for thermal retrofitting that affects the building envelope).
- a legal framework allowing ESCOs to adapt the energy performance contract to operations in buildings owned by the State and local governments must exist.

Today, the majority of ESCOs still do not have enough capital to cover the cost of large-scale retrofitting investment programs. They concentrate on the market for renovations and/or replacement of cooling and heating systems and on lighting, but cannot yet invest heavily in building envelopes. What is more, the energy efficiency market – still in the development phase–is poorly known to the banking and financial sector. This lack of knowledge results in a perception of high risk, especially for projects financed with schemes based on energy performance contracts. This apprehension is naturally reflected in caution granting loans to these types of projects and/or in strict and more economically expensive lending conditions for borrowers compared to the loans granted to more classic projects.

4.2.7. *Manufacturers and distributors of energy efficient equipment and materials*

The interest in initiatives aiming to develop the thermal retrofitting market among manufacturers and distributors of energy efficient materials and equipment is obvious. However, the commercial development strategies of these actors run into different categories of obstacles:

- *Prices:* since energy efficient materials and equipment are generally more expensive than standard materials and equipment with average efficiency, contracting authorities often decide to go with the less expensive versions. What is more, energy service companies – the natural vectors for the distribution of these products – have limited financial means, which causes them to limit over-investment and, therefore, focus on the least expensive components of the energy efficiency programs they recommend (optimized management of heating and cooling systems and lighting).
- *Market access:* the procurement rules for competition between material and equipment suppliers are not always sufficiently transparent, especially in regards to technical criteria for awarding contracts. The lowest bidder remains the dominant deciding criteria, which leaves these new actors little chance of winning contracts.

- *Consumer confidence:* energy efficiency materials and equipments suffer from the lack of a framework guaranteeing their performance with labeling, for example. This situation opens the door to a wide disparity among real performance in the equipment sold on the market. The result, for potential buyers, is a perception of risks that is little conducive to deciding to buy.

4.2.8. *Research and development*

Research and development actors (major schools, universities and laboratories) are recognized by the government authorities as a vital driver behind the adaptation of China's economy to the challenges of energy efficiency and fighting climate change. The motivation of these actors is, among other things, strengthened by the wide variety in fields of research (sociology, economic, technology, pure research, etc.). Despite this strong motivation – which could be seen throughout the research program by constant commitment on the part of the partners from the School of Public Administration and the School of Architecture and Urban Planning from Huazhong University of Science and Technology – the research and development potential in the field of energy efficiency is still too hindered by the walls between disciplines and research, and by a shortfall in communication between the world of research, companies and government institutions.

4.2.9. *Financial institutions*

Financial institutions are the lifeline of economic development. Commercial banks, public development banks and financial companies accompany investors through loans and equity investments. In a context of rapid economic growth, these actors meet the needs of project sponsors while assuming the risk. Thermal retrofitting programs on buildings are seen by financial institutions as a new source of activity generation that can, in particular, become a second pillar of growth in the building sector, alongside promotion and new construction.

If banks' interest in this sector is confirmed, as with energy efficiency investments in industry, the process of understanding the economic and financial project quality assessment criteria (and as a corollary risk assessment) is a long process that requires support. This is, for instance, the case for the FGEF/AFD technical assistance project set up to support the disbursement operations for AFD lines of credit granted to three Chinese banks (Merchant Bank, Shanghai Pudong Development Bank, and Hua Xia Bank) to allocate loans to manufacturers who want to invest in energy efficiency. Among other things, for financial institutions, the profile of this potential relay of growth and development is not yet sufficiently profitable (compared to other types of investments). Accordingly, demand from actors in the sector (building owners and managers, energy service companies, etc.) still needs to grow to allow financial institutions to position themselves proactively on this market.

Many banks have, what is more, set up lines of credit devoted to renovations and energy savings, but these funds go primarily to industry. There are no financial instruments devoted to housing or connected to the central government's soft loan policy. Ultimately, banks' participation in building retrofitting projects accounts for less than 5% of the funds invested.

Finally, while Chinese financial institutions participate actively in financing large-scale real estate operations in new construction, the financing procedures and tools used in this sector do not necessarily fit the needs of retrofitting programs.

4.2.10. *Energy companies*

In the Wuhan urban area, energy consumption – especially electricity (which accounts for more than 60% of energy consumption in the sector) – is growing steadily. This demand puts strong pressure on the supply system and, as we have seen, comes with frequent power rationing and supply shortages. In a minimal planning approach to production capacities, energy efficiency investments – and in particular those that can lessen consumption peaks in the building sector (lighting, heating, air conditioning) – should be evaluated. These assessments should, in a certain number of cases, give priority to investments that limit demand over investments in peak production. This decision, based on the comparison of the cost of the energy saved and the cost of additional energy production, is unfortunately only rarely made by energy operators (in China and the rest of the world, although electricity companies have successfully developed this practice in some states and countries such as Canada and California).

Through the research program, it emerged that the supply culture dominates the decision-making processes of energy companies (the heart of their profession is to sell energy, not save energy) and, consequently, that retrofitting initiatives and programs involving energy companies are unlikely to develop. However, the financial challenges and technical constraints arising from the constantly growing demand make a progressive shift in attitudes possible and reforms in the electricity sector could undoubtedly accelerate this shift.

4.2.11. *Actors' motivation and decision-making capacity*

The analyses above lead to Schema 13, which indicates (from weak to strong) actors' degree of motivation for and degree of discretionary power over energy efficiency retrofitting of buildings.

Schema 13 *Motivation and Discretionary Power: Summary of Actors' Positions*

Actors' Motivation for Building Retrofitting

WEAK			STRONG
• Energy Supply System • Building Owners	• Local Governments • R&D Sector • Unions	• Central Government • Financial Sector • Owners of Commercial Buildings	• ESCOs • Energy Efficient Equipment Suppliers

Actors' Discretionary Power over Building Retrofits

WEAK			STRONG
• ESCOs • Energy Efficient Equipment Suppliers • Unions	• Owners of Commercial Buildings • Building Owners	• R&D Sector • Financial Sector • Energy Supply System	• Central Government • Local Governments

Source: ICE.

In this way, we can see that with the exception of private owners of commercial buildings – for whom the energy bill argument places a constraint on the efficiency and economic profitability of the commercial activity and, consequently, increases interest in lowering this cost – building-owner contracting authorities still have a limited motivation to undertake retrofitting. The main reasons for this slight interest have a lot to do with the non-convergence of interests between the status of owner and that of occupant, and with the fact that, in public sector buildings, the energy bill is often paid (in full or in part) by the supervisory institution. These difficulties add up and intensify with the financial capacity and responsibility of this category of actor.

At the other end of the chain in a retrofitting program, the service suppliers and equipment manufacturers see the interest of an energy efficiency market developing, even though they do not have any direct leverage to influence investment decisions. Thus, setting up financial support schemes that can lighten the responsibility for investment decisions by contracting authorities, and make the service and equipment supply solvent for market actors seems to be a major driver for retrofitting program feasibility.

Central and local governments and institutions are also expected to contribute to the emergence of these new financial systems alongside financial institutions.Their motivation is progressively shifting in this direction but it still needs to grow, at least this is what the various categories of actors expect will happen with the initial results of pilot projects underway in this field.

Part Five

5. Financing programs: existing instruments and innovative mechanisms

5.1. Overview of regional macroeconomic stakes

The research program team conducted audits and feasibility studies to determine the optimal combination of thermal retrofitting measures for different categories of buildings in the city of Wuhan (administrative buildings, office buildings, shopping centers and hotels). Based on the results of these studies and simulations of the cost of possible technical measures, the team defined two investment package options, covering the categories of buildings mentioned above and the overall building stock in Wuhan: the first only covers modernizing energy systems in buildings, while the second covers both the modernization of these systems and building envelope retrofit.

For the categories of buildings listed above, the annual energy savings range from 0.2 Mtoe (energy systems improvement) to 0.37 Mtoe (improving energy systems and renovating the envelope). The corresponding energy bills are cut respectively by 13% and 24%. These savings require an investment ranging from 4.1 billion RMB (for energy systems) to 11.2 billion RMB (energy systems and envelope). The investment recovery times range from 4 years for energy system modernization in hotels and shopping centers, to 8 years for systems improvement in offices (13 years if one adds investments aiming to renovate the envelope of these office buildings), and to 18 years for energy system and envelope renovations on administrative buildings.

In addition to direct energy savings, such a large-scale retrofitting program would have other advantages for the city of Wuhan:

- creation of 14,000 to 40,000 full-time equivalent jobs over the course of the 4-year program implementation period;
- improved comfort for building users;
- stimulation of the construction material, air conditioning and ventilation systems, and general engineering markets; and
- generation of additional budget resources for the central government and local provincial government through the taxes on economic activity.

This reference thermal retrofitting program developed in the city of Wuhan could be replicated, as we showed in Part Three of this document, in Hubei Province and then throughout the Yangtze River basin (covering the provinces of Hubei, Hunan, Jiangxi and Anhui).

5.2. International comparisons

In the building sub-sectors selected for the program, the volume of financial resources to commit is considerable. Internationally, the thermal rehabilitation of buildings in the framework of the Factor 4 [17] target requires the mobilization of financial sums of an equivalent volume. As an illustration, Table 14 presents the financial needs and impacts on employment of large-scale programs in Germany and France in one of the building sub-sectors-residential buildings.

Table 14 *Financing Needs for Housing Retrofitting in Germany and France (in billion €)*

	Germany	France
Factor 4 Investment Needs for the Residential Sector	920	461
Investment per sq. m. (€)	277	206
Annual Investment until 2030	38.3	19.2
Annual Investment until 2050	20.9	10.5
Direct Jobs Created per Year		
Until 2030	722,642	362,420
Until 2050	349,340	197,680

Source: ICE.

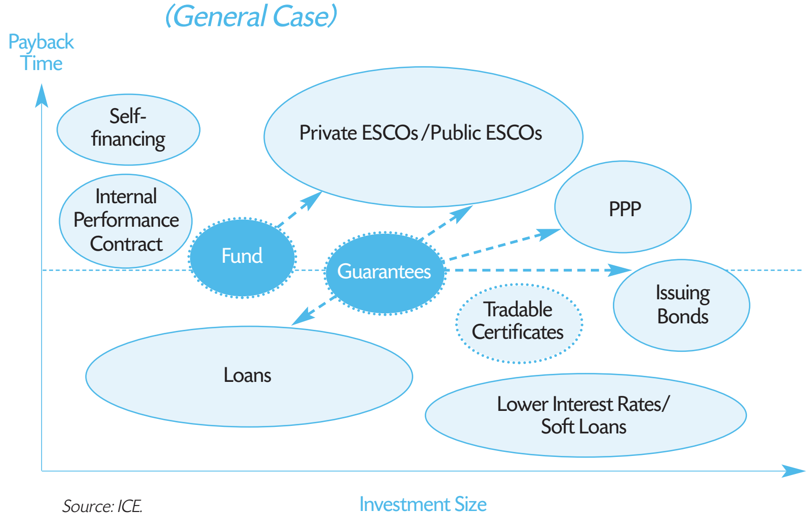
[17] Factor 4 corresponds to the objective, set by France, of lowering its greenhouse gas emissions by a factor of four by 2050, in order to keep global warming below +2°C. The EU has set the goal of cutting its emissions by 30% as its part in an international agreement and has made a firm, and independent, commitment to cut emissions by 20% compared to 1990 levels. On the international level, we are moving toward the acknowledgment of an overall target of cutting global greenhouse gas emissions by 50% by 2050 (compared to 1990 levels).

5.3. Financial challenges

5.3.1. *Matching financing tools and project profiles*

The technical and economic feasibility of implementing large retrofitting programs has now been proven and is generating interest from government authorities. However, the main contracting authorities and key actors (such as the Municipality of Wuhan or the Hubei Province Construction Department), as in most OECD countries, must overcome technical and financial difficulties, which does not allow them to move from the demonstration stage to widespread investment in the sector. A large share of the difficulties is due to the lack of in-house expertise in technical project elaboration; another factor is the limited resources and financing tools to make these operations more attractive to investors (in particular, competitive interest rates and guarantee mechanisms to facilitate lending operations by banks and make terms (loan durations) coincide with project payback time profiles).

Schema 14 *Correspondence between Project Profiles (Payback Times and Size) and Sources of Financing (General Case)*



Source: ICE.

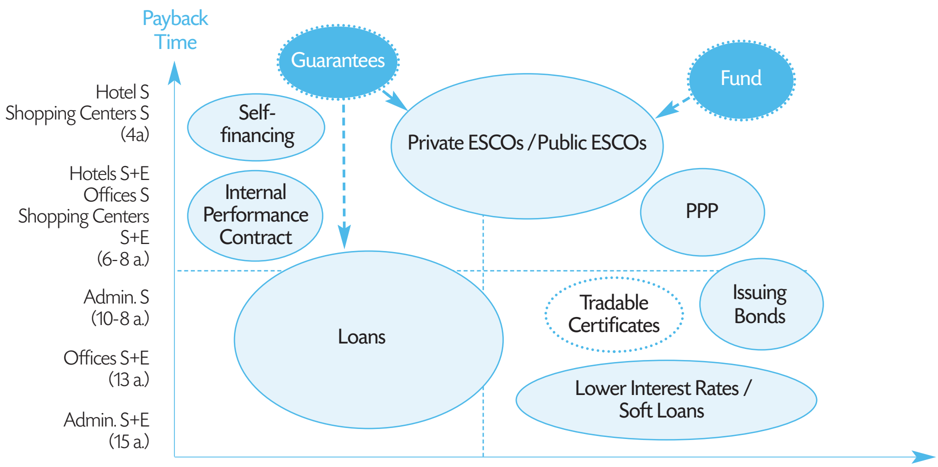
The private sector (engineering and construction companies, local financial institutions, and established or start-up energy service companies (ESCOs)) sees the thermal retrofit market as an opportunity to extend commercial activities and/or offset fluctuations in the new construction market. However, large-scale thermal retrofitting projects in the building sector present certain risks, notably financial risks, that may limit or discourage private sector participation.

One risk is linked to the fact that these projects compete with more traditional investments, which are seen as easier to implement, such as power plant projects and/or industrial development projects. A second risk is due to actors' possible perception of these projects: indeed, they are seen as more risky than energy supply projects because both the quality of the retrofits and equipment substituted and the behaviour of building users can negatively influence energy savings. Among other things, because of the building's legal status (public and/or joint ownership), financial institutions and ESCOs cannot easily, or at all, get sufficient collateral from the assets concerned. Finally, one last risk: these projects have smaller profit margins and longer payback times than investments in other sectors.

In addition to the utilization of suitable financial mechanisms, one necessary condition to support the growth of this market is building technical and financial engineering skills and implementing measures to make intervention by investors and donors more secure.

The research team showed that, depending on the thermal quality profile of a building and its sector of activity, different types of combinations of financial resources could and should be mobilized to meet the needs of actors involved in the rehabilitation (building owners, construction companies, equipment suppliers, ESCOs, etc.).

Schema 15 *Correspondence between Project Profiles (Payback Time and Investment Size) and Sources of Finance (Profiles of the Buildings Studied by the Research Program)*



Source: ICE.
S = Systems; E = Envelope

For example, while investments in retrofits targeting energy systems in hotels have a payback time of four years, which enables the project's financing to be structured based on a combination of self-funding and medium-term commercial loans and/or a third-party financing scheme, the measures recommended for administrative buildings would need to be financed by lines of credit with longer terms and attractive interest rates.

5.3.2. Guidelines to structure a financing plan

The research describing techno-economic energy savings potential in the building stock in the city of Wuhan and Hubei Province showed that implementing large-scale retrofitting programs will require different types of actions:

- target a large range of building categories;
- fit different levels of potential energy savings with diverse combinations of measures and equipment;
- take into account varied investment profiles (size, payback time, risks, etc.);

- involve different actors (owners, renters, users, local governments, etc.);
- attract project promoters and make energy efficiency an attractive market for the building sector;
- mobilize financial resources in amounts compatible with the goals of an ambitious program.

The research team reached the conclusion that, regarding the financial component of large-scale retrofitting programs, it is necessary to offer and/or develop not one but several well-coordinated financial tools or, better, a sufficiently broad and flexible financing mechanism to meet the needs listed above.

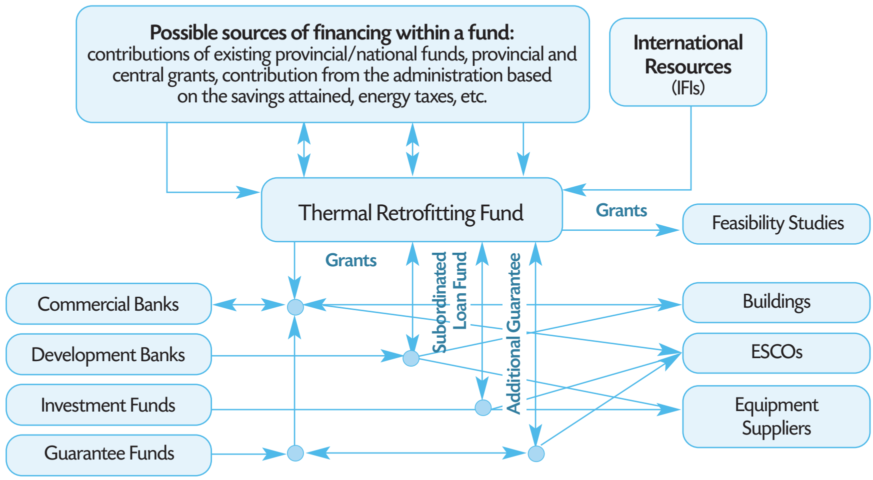
Based on a study of international cases, a comprehensive support mechanism to develop retrofitting programs has been pre-defined. It is based on combining public and private financial resources.

Broadly, the envisaged mechanism consists of diverting some national and local public resources from pre-existing public funds, provincial and municipal budgets, tax revenues, etc. to a thermal retrofitting fund managed by Wuhan and the Hubei authorities. The public funds collected would be combined in the form of grants, supplementary guarantee systems, equity investments and subordinated debt (quasi-equity) with commercial financial resources in order to make the financial products currently offered more attractive (mainly loans and own capital) and encourage the development of innovative financial mechanisms such as the third-party financing system offered by ESCOs.

The form of the fund as presented in Schema 16 is only indicative and should be fine-tuned through discussions with the local, provincial and central authorities. This illustration has the interest of showing the large number of combinations and interactions that can exist between public and private resources with the aim of meeting financing needs: retrofits and retrofitting equipment, as well as the needs of operators (ESCOs, equipment suppliers, banks, etc.) in the form of grants, loans, guarantees, equity and quasi-equity. In the same spirit, this schema suggests the possibility that the central or provincial authorities could mobilize financing lines from international donors and in particular those who have made financing energy efficiency and greenhouse gas emission reduction investments an intervention priority for cooperation and technical assistance.

Schema 16 *Blueprint for the Fund for Thermal Retrofitting of Buildings and Resource Allocation*

Program Proposal



Source: ICE.

5.3.3. *Scale of a thermal retrofitting fund for the city of Wuhan*

Based on the schema above, it was possible to determine the size of a fund devoted to providing financial support to a baseline program corresponding in scope to the program quantified by the research team for the city of Wuhan which represented a total investment of €0.4 billion over a period of four years.

Table 15 *Breakdown of Primary Sources of Finance for the Retrofitting Program*

Sources of Financing: Primary Distribution	Reasonable Market Share of Various Sources of Financing	Value (in M€)	Comments	Secondary Distribution	Value (in M€)
ESCOs	20%	80	of which 20% in own funds and 80% through debt financing	Equity	16
Bank	65%	260		Debt	324
Self-financing	10%	40		Self-financing	40
Public Subsidies	5%	20		Public Subsidies	20
Total	100%	400		Total	400

Source: ICE.

The 4 billion RMB investment value is shared among the main potential sources of financing: public aid, self-funding, bank loans and financing by ESCOs through third part financing contracts. The estimated shares for each of these sources of financing would be 5%, 10%, 65% and 20% respectively. In regard to ESCOs' specific contribution, we assumed that 20% of the value of the performance contracts would be financed with own equity and 80% with loans.

This intermediary calculation allowed us to determine the secondary distribution of financial resources required to meet the program's financial needs:

- public aid (subsidized financing): €20 million;
- self-financing (funding by contracting authorities): €40 million;
- bank loans: €324 million;
- ESCOs: €16 million.

We assumed that the thermal retrofitting fund would provide three types of financial support: *(i)* direct grants to facilitate the elaboration of the feasibility studies necessary to implement a large-scale retrofitting program; and *(ii)* subsidies backed by market financial resources in diverse forms to increase their attractiveness when it comes to cost and terms.

Table 16 shows how the resources in the thermal retrofitting fund could be allocated among the various financial products and tools. A large share of the thermal retrofitting fund's contribution would be in the form of soft loans (€65 million), a financial resource that is renewable in nature. This unique resource could be granted either by the government or the province, or from a line of credit provided by one or more international financial institutions.

Table 16 *Final Distribution of Sources of Financing for the Retrofitting Program*

Products/Tools	Level of Contribution to Market Needs	Corresponding Value (in million euros)
Grants for Feasibility Studies	for 50% of feasibility study costs, up to 5% of the project cost	10
ESCO Support	maximum 35% of own equity/ subordinated loans in the share	6
Soft Loans	20% of total debt needs (financing by project loans + energy service companies' debt)	65
Subsidies for Loans	10% of loans and at most 20% of grants	6
Additional Guarantees	covering 20% of the ESCO market	2
Total resources to be provided by the fund over a period of 4 years		88
of which: *Grants* *Revolving fund*		 16 72
Annual Financial TRF Needs		22
of which: *Grants* *Revolving fund*		 4 18

Source: ICE.

Given the leverage effect of public resources, a €0.4 billion program would require the mobilization by the thermal retrofitting fund, of €88 million, €16 million of which in public grants and €72 million of which in financial resources for lending (*i.e.*, returning to the fund after repayment by borrowers). Each year, the fund's contribution would be split between €4 million in grants and €16 million in finance in the form of loans, subordinated loans and guarantee..

5.4. Organizing scheduling and financing: the collaborative platform

5.4.1. *The consultation platform*

The research done with Hubei Province on energy efficiency in existing buildings led, in its components on institutional and financial issues,[18] to an original proposal, presented at the conference that was held in Wuhan in May 2009:[19] a provincial platform for dialogue and consultation on the elaboration and implementation of the building energy efficiency retrofitting program.

The research, although conducted with excellent cooperation among the Chinese and French experts, revealed two consultation difficulties: first, between official bodies themselves (that, as they do nearly everywhere, reason "vertically" and keep to themselves for the most part); and second, between the public authorities and administrations and "the market", that is to say public and private building owners and the enterprises that will play a role in retrofitting programs (whether consultancy firms, construction companies, material suppliers, and especially banks and other financial organizations).

To overcome the fact that dialogue was nearly impossible, the research program proposed the formation of a "platform" that would bring together in an organized and almost institutional fashion all these partners. The existence of such a platform, combined with a specific large-scale building retrofitting program, seemed to us to be absolutely necessary and the idea was well received among our Chinese partners, in particular during the Circle discussions in November 2009.

[18] Working Groups B and C in the methodology.
[19] "Urban Sustainable Development in Greater Wuhan", May 12-13, 2009 – Workshops B1 and B2, presentations by Professor LI Jing.

5.4.2. *An overall institutional proposal*

Starting from this point, can an institutional proposal be formulated? To do so, it seems to us that certain conditions must come together:

- the creation of such a platform in a province and for a specific program cannot, in our opinion, be decided (in China) without national approval and without a national system that would make it possible to propose a comprehensive approach to the question of the desired State-market coordination; and
- having a platform means that it must be organized and run, and must therefore have the convening power of an acknowledged authority (by the public and private spheres) and the resources needed to operate.

Arriving at a comprehensive institutional proposal from this specific proposal is an original approach, one that is an interesting accomplishment by the research program. Indeed, it is a bottom-up approach based on the requirement of partnership and consultation, as opposed to a top-down approach such as the creation of an agency that is then assigned the mission of dialogue and partnership.

We can say that the basic "unit" in the proposed institutional edifice is the provincial platform on a specific and clearly defined subject (*e.g.* energy efficiency retrofitting of buildings). The heart of the institutional edifice that could be proposed must be public and national in scope, and hold uncontested legitimacy, authority and convening power. This issue must be discussed with the Chinese authorities, but it does seem that such a "place" exists in the NDRC. If this is indeed the case, the provincial branches of this "orchestral conductor" would be entrusted, in each province, with organizing, coordinating and running various platforms on the priority topics in the national energy efficiency policy. The first of these topics would be the energy efficiency retrofitting of buildings and the creation, in one or two regions, of a consultation platform on the subject. The overall approach would be that of an "institutional pilot operation".

The platform system is in no way meant to solve everything. But, in our opinion, it meets the first need – consultation among actors – that, if well organized, should allow each to contribute to elaborating and implementing programs in respect of each actor's skills and functions. Thus, this "facilitating" edifice does not replace any organization or actor, but helps them all participate in a collectively elaborated process.

Conclusion

Conclusion

The research program presented in this publication took place over a three-year period, from the fall of 2006 to the fall of 2009. Covering an entirely new subject in Hubei Province, it helped lay the foundations for a real dynamic of growth in energy efficiency retrofitting of buildings in the city of Wuhan and beyond.

After a series of contacts between the AFD's Research Department and the Hubei Province Construction Department, which led to a cooperation agreement for the joint research program, an initial phase of work focused on the elaboration of methodology proposals by the AFD experts. The proposals were then presented to the Chinese team and were discussed at length, leading to the research program methodology presented in this document.

This phase, essential to establishing the framework for the program as a whole and to set up the working groups, was crucial for creating a climate of trust and mutual understanding among the program participants, the Hubei Province and city of Wuhan administrations, the academics and the AFD team. This dialogue, often lively, showed that, while purely technical questions were well understood, economic, institutional and financial questions were less well understood and that there was a natural tendency to want the research to progress linearly, in consecutive stages. The methodology of a parallel and interactive approach to the various issues – surprising at the start of the discussions – was adopted thanks to an awareness of the importance of a comprehensive and complementary approach (if only to convince decision-makers of the importance of the stakes and the interest to be found in the impacts of retrofitting on all levels).

This difficulty, which can be associated with the transition currently underway in China from a State-planned economy to a market economy (albeit with strong guidance from the government, notably on energy efficiency), is not specific to this context: it can be found in nearly all countries. The open-mindedness that all the partners showed was a decisive factor in the final elaboration of the methodology, progression of the research and outcome of the program, which all serve to validate its relevance.

The second phase of the research program focused on the work of three working groups: technical and economic analysis (Group A), institutional and organizational questions (Group B), and investment financing (Group C). This phase was punctuated by coordination meetings to monitor progress in the research, make adjustments and improve the rest of the program.

Undeniably, the work by Group A was the most advanced, for several reasons.

First, the "art of engineering" is a very well developed discipline in China and there were not any "surprises" in this area on the side of the Chinese partners. The teams were therefore well equipped to conduct their work and the transfer of skills on subjects such as energy audits and simulation models generated a great deal of interest. Economic questions were, however, newer, in particular when it came to assessing the impact of retrofits on all levels, from consumers to society.

The second reason for this success was that, among AFD experts, experience with energy efficiency in buildings in China had already been acquired during prior cooperation (notably in the northern part of the country): AFD had anticipated this program by supporting energy audit training, and the constant presence in China of partners from the TERAO consultancy firm made it possible to participate more closely in this group's work. Finally, the involvement of the Chinese part was in general stronger and more expert than in other groups.

We could see that the approach proposed in the methodology was followed very closely in Group A's work, from the elaboration of the building typology to the impact assessment on large-scale programs in the city of Wuhan and in the Yangtze River basin.

This "degree of satisfaction" explains the length of Part Three of this document (and its Appendices). Indeed, it seemed preferable to clearly show the step by step progression of the research, the level of complexity and precision of the various practices and instruments implemented (energy diagnostic, simulation models, cost assessments, impact calculations), and the quality of the results obtained.

Progress was more difficult on the institutional and organizational questions addressed by Group B. On this subject, the transitional status of China's economy and its consequences on the decision-making structure and involvement of actors played a large role. Indeed, the deeply rooted idea that "everything depends on the State" (*i.e.* the central government and its provincial and local offshoots) led to the importance of the role of other actors (consumers, companies, groups on all levels, financial organizations) and, thus, the importance of partnerships, being ignored. We saw, for example, that the few large-scale thermal retrofitting programs in the northern regions were "ordered from the top" and yet, in a situation where the government was in fact the contracting authority, the question of actors' mobilization arose. The need for partnership is important in a centralized economy, even if it is often ignored or neglected, while in a transition economy, it becomes crucial.

Many discussions took place on these subjects, and considerable work was done by the Chinese research partners on this topic, which was new to them, of identifying partners and analyzing the "interplay among actors" presented in Part Four of this document. This is a question for which the experience of the French experts was valuable because France, despite having a market economy, is a highly centralized country with a powerful public sector, including at utilities level.

This work on identifying actors, analyzing their interests and motivation for energy efficiency retrofitting of buildings is quite original and constitutes a particularly interesting and innovative result of the research program. Indeed, it is this work, in addition to the work on financing issues, that led to the proposal of the "collaborative platform" discussed in Part Five of this document.

The financial issue, addressed by Group C, was probably the newest. The most innovative aspect of the approach was the very fact that financial questions were included in such a research program. While technical questions and economic calculations, and even regulatory issues, are naturally accepted as legitimate in a program such as this, it is very unusual that institutional questions and even more so financial questions are seen as relevant to the research. In general, financial questions are seen as coming "at the end of the line" and not of concern in research, as not being "noble" and as being a "recipe" left to public authorities (who must invest or give grants) or bankers (as long as they are interested in this field of activity).

The reality is entirely different: the question of financing is central if one wants to implement large-scale programs. It is therefore crucial to address financing early on in the process if one wants to avoid running into difficulties and, ultimately, being unable to move from "pilot projects" that were successful thanks to (necessarily limited) public funding to large-scale projects.

The assessment of economic and financial challenges led, therefore, in Part Five of this document, to analyzing existing financing tools and working on adapting them to building energy retrofitting projects. This adaptation remains insufficient in all countries and is notably so in China given the very slight involvement of banks. It is therefore necessary to propose innovative financial instruments that combine the most intelligent intervention possible by public authorities and the mobilization of private finance. Thus, the following steps were proposed: *(i)* the creation of a "building energy efficiency retrofitting fund" for the city of Wuhan; *(ii)* the development of ESCOs able to take charge of and finance investments (following the "third-party financing" principle); and (iii) the intervention of Chinese banks (encouraged by cooperation with IFIs, enabling the establishment of lines of financing devoted to retrofitting operations).

The institutional and financial issues come together in an original proposal, the outcome of the research work (after long discussions), of forming a province-level "collaborative platform" that would be a place for consultation on the elaboration, organization and financing of building energy efficiency retrofitting programs. This decentralized idea (*i.e.* "from the field") – would lead to an overall organizational proposal (*i.e.* country-wide in scope) on running and organizing the partnership.

The third and final phase of the research program consisted of preparing and presenting in detail the research program approach and results during the national conference held in Wuhan on May 12-13, 2009, on the subject of "Sustainable Urban Development in Greater Wuhan" (AFD, 2010). This conference was extended with the organization of the Sino-French Circle on Energy Efficiency in Buildings (October 17-24, 2009, in Paris).

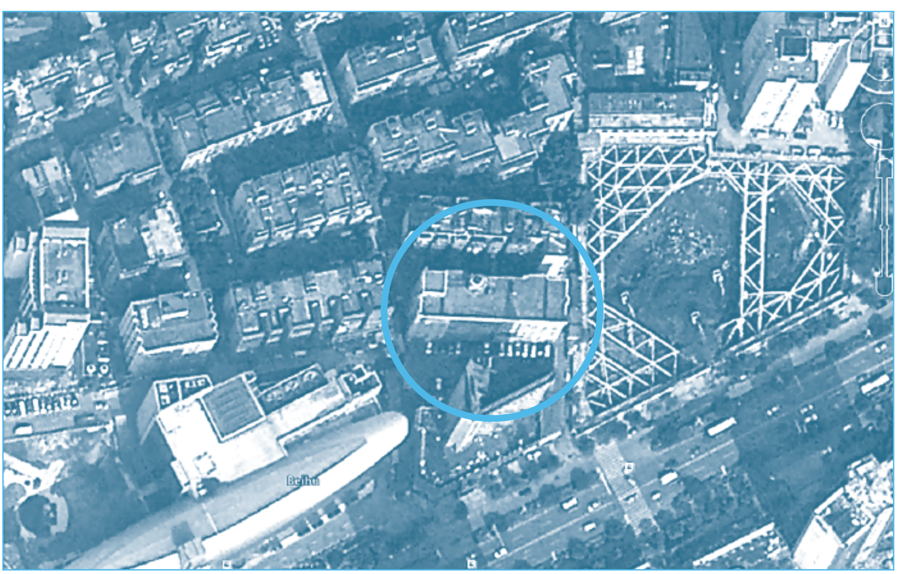
Appendices

Appendix 1.
Collection of data for the audit of the Wuhan City Energy Efficiency Bureau building

General remarks on the neighbourhood and building envelope

The building in question is short (eight floors) and surrounded by a number of buildings, facing different directions, that provide shade protecting it from the sun's rays.

Photo 3 *Satellite Photo of the Wuhan City Energy Efficiency Bureau Building*



Source: Google.

Photos 4 to 7 show the state and design of the building envelope.

Photos 4, 5, 6 and 7 *Wuhan City Energy Efficiency Bureau Building Facades*

4

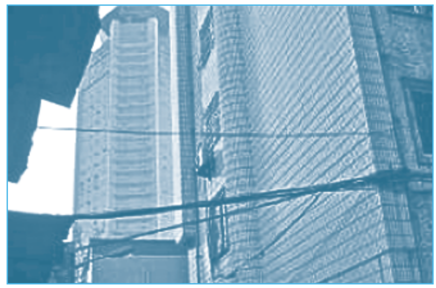

5


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Photo credits: project team.

The facades are moderately covered in windows with a 25% window-to-wall ratio, which is reasonable for Wuhan. The solid walls are not insulated, and the windows are single-pane sliding windows with metal frames. There are no sunshades. This is typical of a building built in compliance with the building code in force in 1980 (before energy regulations were issued, in 2005). Ventilation is natural (no mechanical ventilation), and is accomplished by opening windows. Given the fact that the building is heated and air conditioned, this state of affairs wastes considerable energy.

Surface area data are:

- NFA = 5,617 sq. m
- UFA = 4,700 sq. m.
- Footprint = 700 sq. m.
- The UFA-to-NFA ratio of approximately 85% is frequent.

Occupation data:

The audit revealed occupancy of approximately 400 people as regular occupants. Visitors also contribute. This contribution is not negligible because there are between 500 and 600 visitors per day, spread throughout the day.

The building is occupied from 8:30 a.m. to 5:30 p.m., with a lunch break from 12:30 p.m. to 2:30 p.m. The building is unoccupied on weekends, and there are between 5 and 15 holidays per year, which means the building is occupied 251 days per year.

Other data on internal heat gains

In addition to occupation, it is important to take into account the data on any equipment likely to influence air conditioning and heating consumption, as well as direct electricity use. Typically, in an office building, these contributions come from lighting and computers. There is approximately 13 W/sq. m. of lighting power installed. This value is relatively high for offices; since the lamps use low-consumption bulbs, this number indicates excess lighting.

Most of the offices have computers. Their average operating charge is estimated at 15 W/sq. m., a typical number for offices with medium-density occupation.

Technical installations

Photos 8 to 11 *Wuhan City Energy Efficiency Bureau Building HVAC Installations*

8

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10

11

Photo credits: project team.

Heat and cold production is provided by a absorption system powered by natural gas. Heating and cooling power are each 780 kW. This system's yield is low: COP of 1 in cooling mode and 0.85 in heating mode. The gas burner is recent because fuel was changed; the current generator runs on diesel fuel. The safety precautions for the boiler room are followed (ventilation and gas shut-off). There are two cooling towers on the roof and a 30 kW pump on the cooling circuit. The distribution circuit also has a 30 kW pump. The distribution columns feed secondary circuits that end at fan coils in false ceilings in the offices. In China, this is the most frequent type of terminal unit found in office buildings. Finally, the operation of the installation was done manually by the daily manager; there is therefore no BMS. He sets the water circuit temperatures and anticipates the hours of occupation for heating.

This example shows how data collection allows one to understand existing performance and connect it to billing data.

Appendix 2

Audit of the Hubei University of Science and Technology Hospital as part of an energy consumption diagnosis

A building that is more representative of the samples targeted by large-scale retrofitting is the Hubei University of Science and Technology Hospital; this representativity comes from its size and consumption. It is a favored candidate for retrofitting because it belongs to an energy guzzling category (as we emphasized in the statistics gathered by the surveys of the 389-building sample).

General Description

This hospital is composed of several buildings for a total developed area of 45,761 sq. m. It notably includes hospital wards, consultation rooms, a beauty parlor, administration offices, a cafeteria, and staff housing.

Photos 12 and 13 *Hospital Wards (12) and Consultation Rooms (13) of the Hubei University of Science and Technology Hospital*

12

13

Photo credits: project team.

As with many buildings in Wuhan, the envelope composition is classic, consisting of concrete posts and outside walls in 240 mm red brick. Single-pane windows are found on all sides. The various buildings have 4 to 5 stories, except for the cafeteria which has two stories. The buildings are 15 to 30 meters high.

Specific electrical equipment and other internal Gains

The hospital ward building contains three 11-kW elevators and one 18-kW elevator; the consultation building has two 12-kW elevators. There is lots of medical equipment, which consumes electricity and generates heat.[20]

Here, we have an example of a partial audit because the people in charge of this procedure did not record the installed lighting power or occupation data.

Active systems

There are three steam boilers using coal as fuel. They run year-round, and have a very low yield of approximately 55%. The steam they generate supplies the hot water loop through a plate heat exchanger and the cold water loop through an absorption chiller.

Air conditioning and heating are provided by pre-conditioned fresh air distribution and fan coil terminals. The heating runs 100 days in winter, and air conditioning four months in summer.

The additional uses characteristic of hospital use are the cafeteria, high production of hot water, and sterilization processes. They partially explain the energy guzzling nature of hospital buildings. The user comfort criteria must also be taken into account, as it is much more demanding than in office buildings, for instance. The hospital is heated to 22°C 24 hours a day while office buildings are typically heated to roughly 20°C for 8 hours a day. The system examined is very centralized because it serves the consultation blocks, hospital wards, administration offices and staff housing.

[20] We have an exhaustive list of this equipment but shall not provide this list here as this section is purely illustrative.

Table 17 Installation Operations in the Hubei University of Science and Technology Hospital

Equipment	Type	Reference	Type of Energy	Number
Coal Boiler	DZL6-1.27-A	–	Coal	1
Coal Boiler	DZL4-1.27-A	–	Coal	2
Chiller	TSA-SFC-32	Power: 1,196 kW	Steam	2
Cooling Tower	CTA-400UFWH	Power: 15.2 kW	Electricity	2
Chilled Water Pump	V180L-4	Output: 187 cubic m/h P: 22 kW	Electricity	4
Cooling Pump	V200L-4	Output: 400 cubic m/h P: 30 kW	Electricity	4

Source: project team.

Photos 14, 15 and 16 4-Ton Boilers (14), 6-Ton Boilers (15), and Chilled Water Pumps (16) at the Hubei University of Science and Technology Hospital

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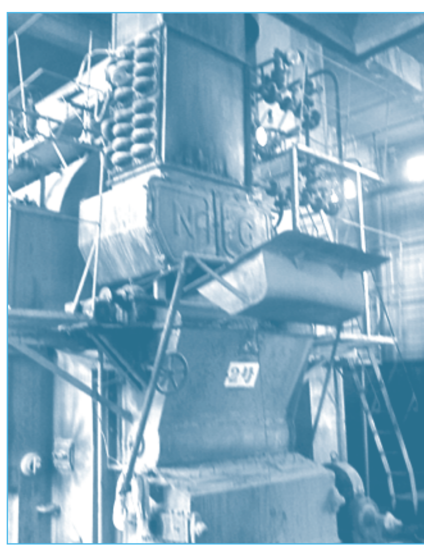

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Photo credits: project team.

Analysis of bills

In order to see the connection between the inventory of envelope elements, active systems and other types of contributors to the energy and thermal balances, one must analyze bill structure in detail. The more that are available, the better. Indeed, for some types of buildings, consumption will be faithfully consistent from one year to the next, while in other cases consumption may vary by 20% for instance. If only one year is available, one must do with it; but when several years' worth of bills are available, relative variations can be assessed and one can see if they are caused by behaviours, changes in equipment, or weather variations. The goal of the exercise is to determine, from these bills, how final energy is broken down by use.

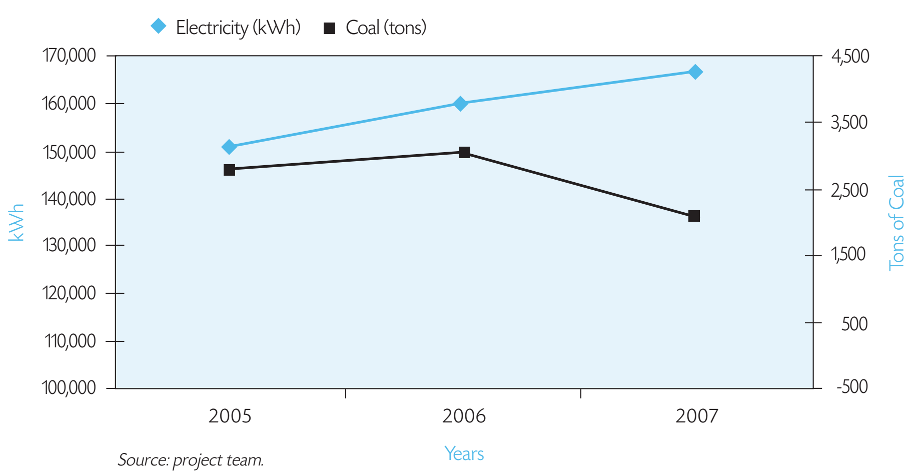
In the case of this hospital, we were able to recover the bills for all of 2005, 2006 and 2007. Annual consumption for each type of fuel is presented in Table 18 and Figure 34.

Table 18 Annual Consumption by Fuel Type at the Hubei University of Science and Technology Hospital

Year	Electricity (kWh)	Coal (tons)
2005	1,504,032	2,793
2006	1,593,135	3,060
2007	1,663,013	2,063
Average	1,586,726	2,639
Uses Concerned	Lighting, medical equipment, ventilation, elevators, computers, televisions	Steam network for heating, disinfection, and food service

Source: project team.

Figure 34 Annual Consumption by Fuel Type at the Hubei University of Science and Technology Hospital



Source: project team.

Electricity consumption is relatively consistent and so was coal consumption in 2005 and 2006. There was a non-negligible drop in 2007, however. We would need to see the 2008 bills to determine whether this drop was an "accident" due to equipment failure or different management, or if it shows a trend of dropping consumption.

The study of large-scale building consumption implies standardizing consumption data. The most frequent standardization is to convert data into built surface units. What is more, in China, the standard consumption unit is the kilogram of coal equivalent (kgce). It is used to express consumption in primary energy. The conversions are done as follows: 1 kWh of electricity = 0.3619 kgce.

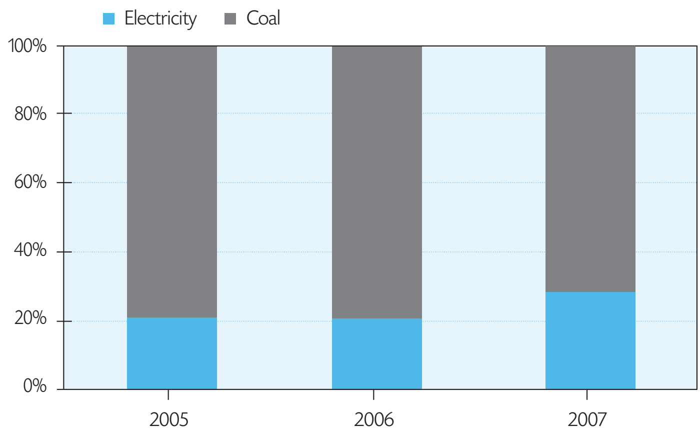
Table 19 *Annual Final and Primary Energy Consumption by Fuel Type at the Hubei University of Science and Technology Hospital*

Year	Electricity		Coal		Total	
	kWh/ sq.m./year (final energy)	kgce/ sq.m./year (primary energy)	kWh/ sq.m./year (final energy)	kgce/ sq.m./year (primary energy)	kWh/ sq.m./year (final energy)	kgce/ sq.m./year (primary energy)
2005	32.9	11.9	61.0	43.6	153.3	55.5
2006	34.8	12.6	66.9	47.8	166.8	60.4
2007	36.3	13.2	45.0	32.2	125.3	45.4
Average	34.7	12.6	57.7	41.2	148.5	53.7

Source: project team.

The bills therefore show that coal consumption is what dominates in final energy, as shown in Figure 35.

Figure 35 *Breakdown of Final Energy by Fuel Type in the Hubei University of Science and Technology Hospital (in %)*

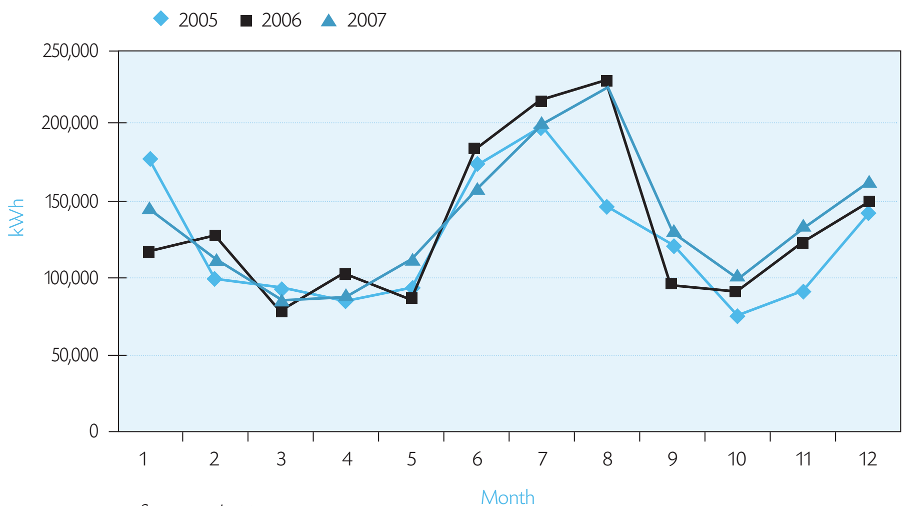


Source: project team.

Coal therefore accounts for 60% to 70% of total final energy consumption, and 70% to 80% of primary energy. Because we are looking at a large-scale retrofitting operation, it is relevant to reason also in terms of primary energy because the combined energy savings from many retrofits can have a non-negligible impact on the energy value chain. In other words: choices as to fuel or which system to renovate can have an impact on the direct greenhouse gas emissions of a city or province, and it is appropriate to include this effect in the process.

Electricity

Figure 36 *Monthly Electricity Consumption at the Hubei University of Science and Technology Hospital*



Source: project team.

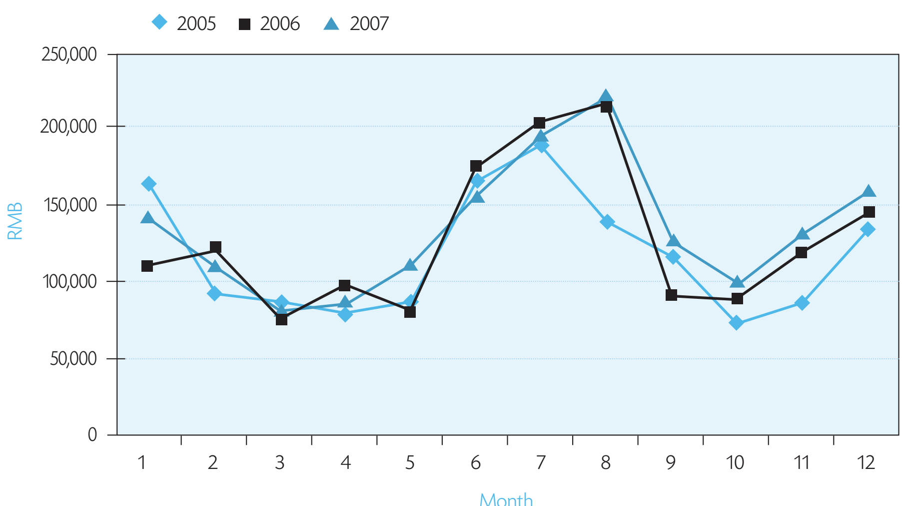
Figure 36 clearly shows that consumption is seasonal. In mid-season, we see basic consumption that is probably consistent from year to year and corresponds to consumption for non-seasonal uses (lighting, medical care, etc.). This basic consumption is approximately 1,000,000 kWh/month. This figure, obtained by adding up the power of equipment for the uses cited above and questioning the manager as to operating times, also allows us to deduce a usage coefficient for the various equipment.

However, we also see consumption peaks in winter and summer. If the summer peak is the highest, this is simply due to the relative weight of heating/air conditioning (approximately 60%). Indeed, in this case, the typology is one of a pre-cooled or pre-heated new air distribution system (called blown at neutral enthalpy) by a central AHU with fan coil terminals to provide the locally desired set temperature (see general description above). The consumption peak corresponds to the fan coils.

This shows that a detailed reading of an energy bill can already provide us with a lot of information and even allows us to verify that the data collected on site is coherent. It is an iterative approach with the building managers to move toward real identification of energy uses.

We can now also analyze the costs generated by these electricity consumptions, an important stage in the energy retrofitting process.

Figure 37 *Cost of Electricity Consumed at the Hubei University of Science and Technology Hospital (in RMB)*



Source: project team.

The average cost of electricity in 2005, 2006 and 2007 was 0.93 RMB/kWh. Slight seasonal variations can be seen: since the cost curve follows the consumption curve fairly accurately, the fan coil system shows its disadvantage in terms of operating costs (because it generates significant additional spending in the summer and winter).

Coal

In regard to coal, only annual data was available.

Table 20 *Annual Coal Consumption and Cost of Consumption at the Hubei University of Science and Technology Hospital*

2005	Coal Purchased (T)	2,793
	Cost (RMB)	1,125,691
2006	Coal Purchased (T)	3,060
	Cost (RMB)	1,229,199
2007	Coal Purchased (T)	2,063
	Cost (RMB)	875,595

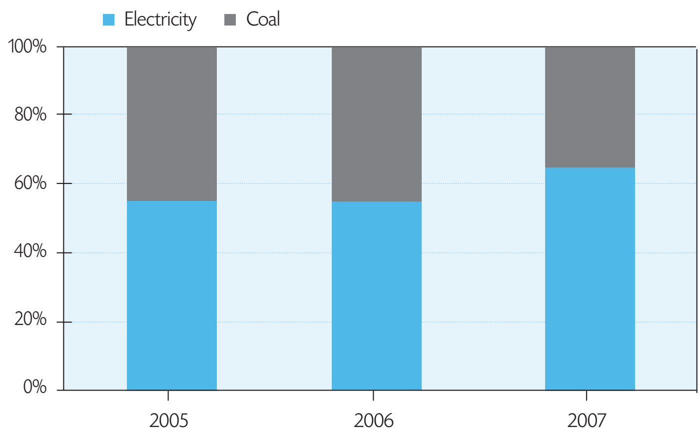
Source: project team.

Coal is a polluting source of energy and coal boilers usually have poor yields. But it is also an inexpensive source of energy: one kg of coal costs 0.40 RMB. Given that one kg of coal is equivalent to 1.4 kWh, the price comes to 0.285 RMB/kWh. Compared to 0.93 RMB/kWh for electricity, we can see that coal is less attractive for energy saving activities. For the same final energy savings, the gross payback time with coal would be 3.3 times longer. This is often prohibitive.

Summary of operating costs

It is now possible to see the relative weight of electricity and coal on total operating costs.

Figure 38 *Breakdown of Operating Costs by Fuel Type at the Hubei University of Science and Technology Hospital*



Source: project team.

While coal accounts for between 60% and 70% of total final energy consumption, it only accounts for approximately 40% of energy operating costs. From the standpoint of energy efficiency retrofitting, efforts should concentrate in priority on the energy guzzling consumption items, or in other words uses linked to coal consumption. However, from the standpoint of economic feasibility, it is probable that actions that lower electricity consumption will be much more attractive, even if they generate smaller energy savings in absolute terms.

Determination of the hospital's consumption profile

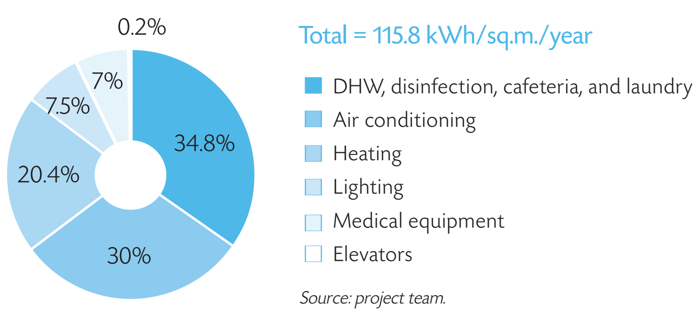
There are different approaches to determining how energy consumption is broken down by use: on-site measurements, installing specific meters, dynamic thermal simulations (see Part Three), or using simplified methods based on installed power, operating time, and usage coefficients.

When this hospital was audited, the simplified method was used. It gives an idea of what is and is not predominant. It is an initial overview to determine which retrofitting techniques would be most appropriate for a given type of building.

In this case, the consumption profile is as follows (based on averages from the three years):

- the uses that guzzle the most energy comprise day-to-day hospital activities (DHW, disinfection, and laundry). Next come air conditioning, heating, lighting, medical equipment and elevators.
- for their part, the specific uses that guzzle the most energy make up the area where technologies specific to the hospital could be envisaged (recovering heat from wastewater).
- it is, of course, a case where lowering consumption from air conditioning is a priority.

Figure 39 *Breakdown of Final Energy Uses at the Hubei University of Science and Technology Hospital*



Source: project team.

Here, we can note an important point: the air conditioning and heating categories include the consumption of their auxiliaries.

In conclusion for this example, we see how a detailed audit allows one to establish a true diagnosis of energy consumption. Based on this profile, more precise investigations can be conducted on possibly poorly adjusted systems, and thermal simulations can be conducted to determine the relative weight of the poor quality of the envelope on this state of affairs. This work makes it possible to "prepare the field" for the elaboration of proposed improvements. This method therefore makes it possible to go far beyond what the preliminary surveys had been able to establish.

Acronyms and Abbreviations

Acronyms and Abbreviations

ADEME	*Agence de l'Environnement et de la Maîtrise de l'Énergie* (Environment and Energy Control Agency)
AFD	Agence Française de Développement (French Development Agency)
AHU	Air Handling Unit
BESRRU	Bureau of Energy Savings and Rational Resource Use
BMS	Building Management System
CMV	Controlled Mechanical Ventilation
COP	Coefficient of Performance
DHW	Domestic Hot Water
DRC	Development and Reform Commission
EMCA	China Energy Management Company Association
ERI	Energy Research Institute
ESCO	Energy Service Company
ESE	Energy Service Enterprise
ETH	*Eidgenössische Technische Hochschule* (Swiss Federal Institute of Technology Zurich)
EU	European Union
FGEF	French Global Environment Facility
GDP	Gross Domestic Product
HP	Heat Pump
HVAC	Heating, Ventilation, and Air Conditioning
IEA	International Energy Agency
IFI	International Financial Institution
IPAC	Integrated Policy Assessment Model for China

ISI	*Fraunhofer Institut für System und Innovations* (Fraunhofer Institute for Systems and Innovation Research)
KGCE	Kilogram of Coal Equivalent
LVEP	Low-Voltage Electrical Panel
MOHURD	Ministry of Housing and Urban and Rural Development
NDRC	National Development and Reform Commission
NFA	Net Floor Area
ODA	Official Development Assistance
OECD	Organisation for Economic Cooperation and Development
RMB	Renminbi (Chinese currency)
TCE	Ton of Coal Equivalent
TOE	Ton of Oil Equivalent
UFA	Usable Floor Area
VAV	Variable Air Volume
WG	Working Group

Bibliography

Bibliography

AFD (2010), "Implementing Large-Scale Energy Efficiency Programs in Existing Buildings in China", proceedings of the conference organized by the Agence Française de Développement and the Commission of Housing, Urban and Rural Development of Hubei Province, in Wuhan (China), on May 12–13, 2009, *Conférences & Séminaires 01*, AFD, Paris (document available for download from the AFD's website).

AFD and IEA (2008), *Promoting Energy Efficiency Investments: Case Studies in the Residential Sector,* OECD, IEA and AFD, Paris (document available for download from the IEA's and the AFD's websites: http://www.iea.org/textbase/nppdf/free/2008/PromotingEE2008.pdf).

Chevalier, J.-M. (2004), *Les grandes batailles de l'énergie,* Gallimard, Paris.

Chevalier, J.-M., P. Barbet and L. Benzoni (1986), *Économie de l'énergie,* Presses de la Fondation Nationale des Sciences Politiques, Paris.

Debeir, J.-C., J.-P. Deleage and D. Hemery (1986), *Les servitudes de la puissance : une histoire de l'énergie,* Flammarion, Paris.

Dessus, B. (1999), *Énergie, un défi planétaire,* Belin, Paris.

Enerdata-Lepii-Epe (2005), *Étude pour une prospective énergétique concernant la France,* Ministry of the Economy, Finances and Industry, Paris.

European Commission (2005), *Doing More With Less: Green Paper on Energy Efficiency,* COM 265 final, Brussels.

Global Chance – Negawatt (2010), « Du gâchis à l'intelligence, du bon usage de l'électricité », *Les Cahiers de Global Chance,* n° 27, Meudon.

Goldemberg, J., T. Johansson, A.K. Reddy and R. Williams (1987), *Energy for a Sustainable World,* World Resources Institute, Washington, D.C.

Groupe Confederal Energie CFDT (1984), *Le dossier de l'énergie,* Le Seuil, Paris.

IEA (2005), *World Energy Outlook,* Paris.

IEA, *World Energy Outlook* series (annual publication), *Energy Technology Perspectives* *and IEA Country Reviews* (IEA member countries and a selection of non-member countries); available for consultation on the website: http://www.iea.org/publications

LAPONCHE, B. (2004), *Maîtriser la consommation d'énergie,* Le Pommier, Cité des Sciences et de l'Industrie, Paris.

LAPONCHE, B., B. JAMET, M. COLOMBIER and S. ATTALI (1998), *Energy Efficiency for a Sustainable World,* ICE, Paris.

LOVINS, A. (1975), *World Energy Strategies,* Harper Business, New York.

MARTIN, J.-M. (1990), *L'économie mondiale de l'énergie,* La Découverte, Paris.

SALOMON, T. and S. BEDEL (1999), *La maison des négawatts,* Terre Vivante, Mens.

VON WEIZSÄCKER, E., A. LOVINS and H. LOVINS (1997), *Factor Four,* Earthscan, London.

Sites Internet

ADEME, AGENCE DE L'ENVIRONNEMENT ET DE LA MAÎTRISE DE L'ÉNERGIE: www.ademe.fr

AFD, AGENCE FRANÇAISE DE DÉVELOPPEMENT: www.afd.fr

ATEE, ASSOCIATION TECHNIQUE ÉNERGIE ENVIRONNEMENT: www.atee.fr

ECEEE, EUROPEAN COUNCIL FOR AN ENERGY EFFICIENT ECONOMY: www.ecee.org

ENERDATA S.A.: www.enerdata.fr

ENERGY CITIES: http://www.energy-cities.eu/

ENERTECH – CABINET SIDLER: www.enertech.fr

EUROPEAN UNION: www.ec.europa.eu

GLOBAL CHANCE: www.global-chance.org

IEA, INTERNATIONAL ENERGY AGENCY: www.iea.org

NÉGAWATT: www.negawatt.org

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What is AFD?

Agence Française de Développement (AFD) is a public development finance institution that has been working to fight poverty and support economic growth in developing countries and the French Overseas Communities for seventy years. It executes the policy defined by the French Government.

AFD is present on four continents where it has an international network of 70 agencies and representation offices, including 9 in the French Overseas Communities and 1 in Brussels. It finances and supports projects that improve people's living conditions, promote economic growth and protect the planet: schooling for children, maternal health, support for farmers and small businesses, water supply, tropical forest preservation, fight against climate change, among other concerns.

In 2011, AFD approved nearly €6.9 billion to finance activities in developing countries and the French Overseas Communities. The funds will help get 4 million children into primary school and 2 million into secondary school; they will also improve drinking water supply for 1.53 million people. Energy efficiency projects financed by AFD in 2011 will save nearly 3,8 million tons of carbon dioxide emissions annually.

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Energy Efficiency Retrofitting of Buildings – Challenges and Methods

Energy efficiency retrofitting of existing buildings was long ignored by public authorities who favored energy efficiency policies in new buildings, which are easier to implement. Indeed, retrofitting is more complex and difficult to organize because of the extreme diversity in existing buildings, administrative situations and occupation. Elaborating thermal retrofitting programs of course requires good technical knowledge; but it also requires one to pay greater attention to local economic, social and institutional situations. Energy efficiency retrofitting of existing buildings has now become indispensable in all economies–even emerging countries–given the constraints imposed by energy security and climate change, and because it represents considerable potential energy savings.

This document, based on the experience acquired during a three-year applied research program conducted by the AFD and Hubei Province in China, describes the methodology used through a step-by-step illustration of its application in a real case. This methodological framework can of course be applied to other regions or other countries.

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