DEVELOPMENT OF CHINA'S ENERGY EFFICIENCY DESIGN STANDARD FOR RESIDENTIAL BUILDINGS IN THE "HOT-SUMMER/COLD-WINTER" ZONE

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ABSTRACT

To respond to increasing energy use in the building sector, China has a national effort to develop Energy Codes for building construction. Several years ago, an Energy Code was promulgated for the northern portion of the country, where energy consumption for heating is the primary concern. In 2000-2001, an Energy Code was developed for residential buildings in the "Hot-Summer/Cold-Winter" Zone along the Yangtze River. The Compiling Team consisted of representatives from key cities within the region (Chongqing, Shanghai, Wuhan, Nanjing and Chengdu). International support was provided by the Energy Foundation, the Natural Resources Defense Council, and the Lawrence Berkeley Laboratory.

This work was complicated by the fact that the "Hot-Summer/Cold-Winter" Zone area has both significant heating and cooling loads. Consequently, the "Hot-Summer/Cold-Winter" Zone Energy Code needed to be more sophisticated than the previous Energy Code adopted in China. In addition to balancing the relative importance of heating and cooling loads, the project also involved a judgment of how comfort conditions in residential buildings might be expected to improve over time. The range of energy efficiency measures that were evaluated is presented (including multiple glazing, frame and shading options for windows, and insulation options for the walls and roof). The weather data used is summarized in a companion paper [1]. Key aspects of the code format, compliance options, and requirements are outlined.

INTRODUCTION

The China Ministry of Construction (MoC) has been formulating Energy Standards for building construction since the early 1980's. The first focus of standards was the colder North regions of the country: the "rigid cold" and "cold" zones. "Energy Saving Design Standards of Civil Architecture (Heating and Residential Section) JGJ26-86 was published in 1985 with a goal of 30% energy savings compared to the common local standards prevailing in 1980. The China MoC developed revisions to this standard that took effect in July 1996 with a targeted energy saving rate of 50%.

The climate in the central part of China is characterized as "hot-summer/cold-winter" (sometimes referred to as the "Transition Zone"). This region refers to the middle part of the Yangtze River, an area with a population of 400 million people. The average outside temperature during the hottest summer month is 25-30 C, with peak temperatures above 40 C. The average outside temperature during the coldest winter month is 0-10 C, with lowest temperatures below 0 C. Indoor temperatures can reach 34 C in the summer, and are 10 C or below in the winter.

With the rapid growth of China's economy, residents have taken steps to improve their indoor climate by increasingly adding electric heaters and air conditioners. Because the buildings are uninsulated and the heating and cooling equipment has a low-efficiency, electricity consumption has increased substantially. In addition to affecting the performance of the electrical network, there are environmental impacts from the use of coal both in terms of air pollution and global warming due to carbon dioxide (CO_2) emissions.

In response, the China MoC in Document 309 (12 December 1999) approved a proposal and allocated funding for the development of Energy Standards for residential buildings in the "Hot-Summer/Cold-Winter" Zone. Relevant domestic companies in China also sponsored the work. In addition, internationally, the Energy Foundation of the U.S. (though its Sustainable Energy Program) provided funding and the Lawrence Berkeley National Laboratory (LBNL) of the U.S. provided technical support. The China Academy of Building Research (CABR) in Beijing and the Chongqing Architecture University (CQAU) in Chongqing were designated as the Chief Compilers of the Energy Standards.

COMPILING GROUP MEMBERSHIP AND OVERALL WORK PROGRAM

The Compiling Group consisted of a range of construction industry sectors and from various cities in the "Hot-Summer/Cold-Winter" Zone. Participating organizations included: CBEEA (China Building Energy Efficiency Association) , Tongji University, Shanghai Construction Research Institute, Southeast University, Jiangsu Construction Research Institute, Wuhan Office of Energy Efficiency in Buildings, Wuhan Construction Engineering Research and Design Institute, Chongqing Construction Technology Development Center, Southwest Construction Design and Research Institute, Office of the Walling Material Innovation and Energy Conservation of Buildings of Chengdu, Beijing Zhongjian Construction Technology Institute, Shanghai Technology Center of Owens Corning Asia-Pacific, Beijing Zhenli High Tech Co., and Shanghai Aidishi Indoor Air Quality Tech Co., Ltd.

The development of the “Hot-Summer/Cold-Winter” Zone Energy Code for Residential Buildings took place during a period of 14 months. The Compiling Group had five official meetings with the following tasks:

- March 2000 (Beijing): Identify main principles of code development, identify background research to be completed by each city.
- August 2001 (Dujiangyan): Review results from parametric energy analyses done using the DOE2 program, receive training on use of the DOE2 program.
- November 2001 (Wuhan): Compiling Group discussion of first draft of text and criteria for the TZ Residential Energy Code.
- February 2001 (Nanjing): Review comments from technical experts.
- April 2001 (Shanghai): Final review of comments and approval.

To ensure the development of the most workable Energy Code, international organizations provided support for other meetings and training. These included:

- March 2000 (Beijing): World Bank Seminar on energy efficiency in buildings; workshop to discuss the feasibility of using DOE2 for code development.
- May 2000 (San Francisco, Berkeley, Sacramento, and Rocklin, California, USA): Natural Resources Defense Council (NRDC) sets up and coordinates Chinese Building Code Experts Study Tour to familiarize the Chinese with the development, administration and enforcement of building codes as undertaken in the United States. Included process by which various stakeholders are included in the development process and how their views are reconciled. Questions addressed during this tour included: (1) How the technical requirements of the codes are established, and how they are measured/verified. (2) How to build industry awareness and acceptance of building energy efficiency codes. (3) How to finance code development, administration and enforcement. (4) What personnel requirements, with what sorts of skills, are desired for code administration and enforcement.
- June 2000 (San Francisco, USA): NRDC hosts meeting to discuss DOE2 computer modeling assumptions.
- June-July 2000 (Berkeley, USA): Lawrence Berkeley National Laboratory (LBNL) provides training on DOE2 energy analysis program, assists with development of baseline for “Hot-Summer/Cold-Winter” Zone building construction, and initial parametric analyses of various energy efficiency options.

CODE FORMAT AND CONTENTS

Compiling Group members reviewed background material from key cities (Shanghai, Nanjing, Wuhan, Chongqing, Chengdu) where Energy Codes for Residential Buildings had been completed and adopted or were in the process of development:

- Chongqing Code – promulgated on 1 June 1999.
- Chengdu regulations – passed the review on 11 August 2000.
- Wuhan regulations – promulgated on 1 September 2000.
- Shanghai Design Standards – promulgated on 1 October 2000.

The Compiling Group agreed that the Energy Code should contain prescriptive and performance options for compliance. The overall outline is as follows:

1. General Provisions
2. Technical Terms
3. Interior Design Criteria
4. Overall Energy Consumption Indices
5. Building Envelope Design
6. HVAC Design

   Appendices

An Explanation of the Articles is to be attached.

Section 1, General Provisions, indicates that the Energy Code applies to design and construction of both the building envelope and the heating, ventilating, and air conditioning (HVAC) system. Section 2, Technical Terms, provides definitions for key terminology used. Section 3, Interior Design Criteria, specifies temperatures and air change rates for heating and for cooling. Section 4, Overall Energy Consumption Indices, contains the performance criteria for the overall building in terms of mean load during the peak month and annual energy consumption. These criteria are specified separately for heating and cooling. Section 5, Building Envelope Design, lists the prescriptive criteria for each component of the building envelope. Section 6, contains the prescriptive criteria for the HVAC system.

METHODOLOGY FOR SETTING ENERGY EFFICIENCY CRITERIA

The Compiling Group at its first meeting established a goal of a 50% improvement in energy efficiency (identical to that in the colder North regions of China), at an incremental construction cost of approximately 10%. The percentage improvement in efficiency was to be based on total space heating and space cooling consumption. The baseline building would have single-glazed windows in a metal frame, an uninsulated brick wall 240 mm thick, and a hollow, uninsulated roof. The space heating system was an electric radiator with a COP of 1.0 and the space cooling system was an air conditioner with a COP of 2.2.

Previous Energy Codes for the colder North regions of China were based on a simple analysis of space heating loads. However, this would not work well in the "Hot-Summer/Cold-Winter" Zone because it has both significant space heating and space cooling loads. To simply optimize for space heating alone and for space cooling alone would lead to conflicting results. Consequently, it would be necessary to optimize for the overall year considering both space heating and space cooling. To do this, the energy efficiency criteria would be developed based on hour-by-hour annual energy analyses using the DOE2 software and appropriate weather data [1].

Two buildings were chosen as base cases for modeling purposes. Each was a six-story building with floors 2-5 as identical. The total floor area for each building was roughly 1 250 m^2 and 1 450 m^2, and the floor area in each dwelling unit was approximately 100 m^2. These were felt to be representative of the housing being built in the "Hot-Summer/Cold-Winter" Zone as a whole. (While taller buildings are being constructed in large cities, smaller ones are being constructed in outlying areas.)

The window area in the model was 25-30% of the projected gross wall area (area as seen in an elevation view) for the two facades that had glazing. This was close to the 30% average value for the thirteen projects cited in Table 7.0.2 in the Explanation of the Articles that accompanied the Chongqing Residential Energy Code. (Both end walls were blank with no windows.) It was estimated that 60-70% of the windows in Chongqing had fixed overhangs (though these were installed to keep the rain from coming in leaky windows, not for solar shading). Consequently, fixed overhangs were modeled in the base case.

The units were modeled with four people: two parents and one child, with a third adult to take care of the child. There are separate occupancy schedules for each room. Each room is modeled as a separate zone:

- The three bedrooms, the living room and the dining room are modeled as heated to 18 C (65 F) and cooled to 26 C (79 F).
- The kitchen, bathroom, and stairwell are modeled as unconditioned with no heating or cooling, but with kitchen and bathroom both having an exhaust fan.

Selection of the temperatures required a substantial amount of judgment. Using typical current interior temperatures did not seem appropriate. As the standards of living rise, people want a greater level of comfort where they live, and this Energy Code must be applicable to buildings constructed a number of years in the future. On the other hand, using typical Western interior design temperatures of 21 C (70 F) and 24 C (75 F) did not seem reasonable either. The values selected fall somewhere in between.

The assumptions about windows and temperature setpoints were significant factors in the effectiveness of the various energy efficiency measures. The assumptions of blank east and west facades (no windows) and fixed overhangs over all the windows had a significant impact on the space heating and space cooling loads for the model. For instance in Chengdu, the space heating loads for the entire building were six times as large as the space cooling loads.

Because of the importance of the interior temperature, parametric analyses were done for several interior temperatures. Due to the dominance of the space heating load cited above, the analyses showed that the results are much more sensitive to changes in interior heating setpoint than to changes in cooling setpoint. For instance in Chengdu, raising the interior space heating setpoint temperature to 20 C (68 F) would increase the space heating energy consumption by 26%, and thus provide a 26% higher base to measure savings against. On the other hand, lowering the interior space heating setpoint temperature to 16 C (61 F) would decrease the space heating energy consumption by 24%, and thus provide a 24% lower base to measure savings against. Either of these changes is more significant than the <u>total</u> space cooling energy consumption. However, lowering the interior space cooling setpoint temperature to 25 C (77 F) would increase the space cooling energy consumption by 37%, and thus provide a 37% higher base to measure savings against. On the other hand, raising the interior space cooling setpoint temperature to 27 C (81 F) or 28 C (82 F) would decrease the space cooling energy consumption by 30% or 53%, respectively, and thus provide a 30% or 53% lower base to measure savings against.

ENERGY EFFICIENCY OPTIONS EVALUATED

As indicated above, space heating was the dominant load. For instance in Chengdu, the key components of the space heating load were: 60% wall, 18% windows, 18% roof. The key components of the space cooling load were: 69% windows, 23% walls, 8% roof. Consequently, the wall criteria is shown first, followed by windows, then roof.

The wall was assumed to be a heavy masonry. For walls, fifteen options were evaluated consisting of different combination of several materials (with thickness in m, conductivity, density, and specific heat listed in that order in parentheses): mortar1 (0.02, 0.93, 1800, 1050), brick (0.24, 0.87, 1800, 1050), mortar2 (0.02, 0.87, 1700, 1050), hollow brick (0.24, 0.58, 1400, 1050), insulating mortar (0.025, 0.29, 800, 1050), polystyrene board (0.030, 0.042, 30, 1380), polystyrene board (0.050, 0.042, 30, 1380), polystyrene board (0.080, 0.042, 30, 1380), concrete in cast (0.18, 1.74, 2500, 920), air space (0.02, resistance=0.15), gypsum board (0.012, 0.33, 1050, 1050), concrete block (0.12, 1.76, 2500, 1050), and water-proof blanket (0.01, 0.17, 600, 1470). The resultant U-factors ranged from 2.96 W/m^2K down to U-0.42 W/m^2K.

For windows, six options were evaluated (glass, frame, DOE2 glass type code):

1. U-6.65 W/m^2K, SC-1.00 (clear, single-glazing in a steel frame)
2. U-4.70 W/m^2K, SC-1.00 (clear, single-glazing in a PVC frame)
3. U-3.29 W/m^2K, SC-0.88 (clear, double-glazing in a steel frame, DOE2-2000)
4. U-2.90 W/m^2K, SC-0.84 (clear, double-glazing in a PVC frame, DOE2-2600)
5. U-1.34 W/m^2K, SC-0.32 (tinted, low-emissivity, double-glazing in a vinyl frame, DOE2-1668)
6. U-1.35 W/m^2K, SC-0.15 (reflective, low-emissivity, double-glazing in a vinyl frame, DOE2-2865)

The roof was assumed to be without a ventilated attic (though some have a ventilated flat air space). For roofs, seven options were evaluated consisting of different combination of several materials (with thickness in m, conductivity, density, and specific heat listed in that order in parentheses): concrete board (0.03, 1.74, 2400, 920), air space (0.18 resistance=0.12), slag (0.07, 0.56, 1300, 1050), hollow concrete board (0.12, 1.75, 2500, 1050), polystyrene board (0.020, 0.042, 30, 1380), polystyrene board (0.030, 0.042, 30, 1380), polystyrene board (0.050, 0.042, 30, 1380), water-proof blanket (0.01, 0.17, 600, 1470), and cast-in-place concrete (0.11, 1.74, 2500, 920). The resultant U-factors ranged from 1.66 W/m^2K down to U-0.45 W/m^2K.

PRESCRIPTIVE AND PERFORMANCE COMPLIANCE OPTIONS

Table 1 contains the prescriptive compliance option for building envelope components. The requirements are as follows:

- Walls: $k \leqslant 1.5$ W/m^2K (hollow brick with no insulation, an improvement over the solid brick used in the base case)
- Windows: $k \leqslant 4.7$ W/m^2K (single-glazing in a PVC frame)
- Roofs: $k \leqslant 1.0$ W/m^2K (20 mm polystyrene board insulation)

To moderate temperature swings, a heat tardiness factor D no less than 3.0 (equal to 240 mm clay bricks) is also required. The expected shifts in construction are to hollow brick from solid brick for the walls, to single-glazing in a vinyl frame instead of a steel frame for windows, and to 20 mm polystyrene board insulation from no insulation for roofs. The prescriptive criteria also presume a shift to heat pumps as the primary HVAC equipment with a COP of 1.9 for space heating and a COP of 2.3 for space cooling.

As a comparison, ASHRAE/IESNA Standard 90.1-1999 [2] provides the following prescriptive criteria in Table B-11 for the climates in the "Hot-Summer/Cold-Winter" Zone:

- Walls: $U \leqslant 0.71$ W/m^2K (R-1.3 rigid insulation (50 mm) added to the wall)
- Windows: $U \leqslant 3.3/3.8$ W/m^2K, $SHGC \leqslant 0.39$ (double-glazing w/low-emissivity coating having an emissivity of e-0.05 in a metal frame)
- Roofs: $U \leqslant 0.20$ W/m^2K (R-5.3 loose fill insulation (240 mm) added to attic)

Table 2 contains the performance criteria. Criteria is specified separately for space heating and for space cooling for both mean load in the coldest/hottest months and annual energy consumption. The criteria vary by climate. The criteria were developed using regression equations from the DOE2 analyses.

The next step will be to develop an implementation program so that the desired improvements in energy efficiency will be achieved.

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REFERENCES

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2. American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), "Standard 90.1-1999, energy standard for buildings except low-rise residential buildings", published by ASHRAE, 1999.

Table 1 Prescriptive requirements for building envelope components - average thermal transmission coefficient (k in W/(m^2 • K)) and heat tardiness index (d)

Roof	Exterior wall	Windows[1] (including balcony door fenestration)	Partition wall and floor	Raised floor (natural ventilation below)	Entrance door
k≤1.0 d≥3.0	k≤1.5 d≥3.0	k≤4.7	K≤2.0	k≤1.5	k≤3.0

[1] Window area not to exceed 30% of the south wall area, 25-30%% of the north wall area, and 10% of the east and west wall area. (Window area on the east and west wall allowed to be increased to 25% if vertical shading is provided.)

Table 2 Performance requirements for overall building - building heat loss index & annual electricity consumption for heating and building cool loss index & annual electricity consumption for air-conditioning

Heating Criteria			Cooling Criteria		
HDD18	q_h (W/m^2)	E_h (kWh/m^2)	CDD26	q_c (W/m^2)	E_c (kWh/m^2)
800	14.0	17.1	25	11.1	6.9
900	14.9	19.7	50	12.6	8.4
1000	15.7	22.2	75	14.0	9.8
1100	16.5	24.7	100	15.5	11.3
1200	17.3	27.3	125	17.0	12.8
1300	18.1	29.8	150	18.5	14.3
1400	18.9	32.4	175	20.0	15.8
1500	19.7	34.9	200	21.5	17.3
1600	20.5	37.4	225	22.9	18.7
1700	21.3	40.0	250	24.4	20.2
1800	22.1	42.5	275	25.9	21.7
1900	23.0	45.1	300	27.4	23.2
2000	23.8	47.6			
2100	24.6	50.1			
2200	25.4	52.7			
2300	26.2	55.2			
2400	27.0	57.8			
2500	27.8	60.3			