Forecast of CO₂ Emissions from Construction and Operation of Buildings in Japan Up to 2050

Toshiharu Ikaga¹, Shuzo Murakami², Shinsuke Kato³ and Yasuyuki Shiraishi⁴

¹General Manager of Environmental Engineering Group, Nikken Sekkei Ltd, Japan
²Professor, Faculty of Science and Technology, Keio University, Japan
³Professor, Institute of Industrial Science, University of Tokyo, Japan
⁴Lecturer, Dept. of Environmental Space Design, Faculty of Environmental Eng., University of Kitakyushu, Japan

Abstract
It is estimated that a third of carbon dioxide (CO₂) emissions in Japan are created from construction and operation of buildings, and the construction industry is largely greatly responsible for this. Based on future population projections, a building floor area equivalent to that of Europe, the floor area of buildings already started, and an input and output analysis, a forecast of buildings-related CO₂ emissions has been made up to 2050. If the current situation continues, CO₂ emissions for the period 2008-2012 will rise by 15% compared to 1990 levels. On the other hand, if energy conservation measures are taken along with steps to prolong the life of buildings, reducing CO₂ emissions by 30% in new construction work and by 15% in renovation work, and if the unit CO₂ emission from electricity is reduced by 20% compared to 1990, CO₂ emissions could be reduced by 6% over the period 2008-2012 and by 40% by 2050. We also examined the problems faced by the construction industry, making estimates classified by steps taken by the construction industry, steps taken by the power industry, and the year in which counter-measures are launched.

Keywords: greenhouse gases; Kyoto Protocol; life cycle assessment

1. Introduction
Buildings-related CO₂ emissions, covering the manufacture of building materials, construction, renovation and use of houses and other buildings, account for one third of Japan’s total CO₂ emissions. It is essential to enhance the durability of buildings, a main component on the road to a sustainable society. For that purpose, it is important to set concrete numerical targets for how much the environmental burden needs to be reduced, in all the stages of a building’s life cycle, that are appropriate for the main component of a sustainable society. The Intergovernmental Panel on Climate Change (IPCC) has presented targets for “global CO₂ emissions to be reduced by one third of 1990 levels by 2100 to avoid serious consequences for the human species.” The United Nations Framework Convention on Climate Change (UNFCCC) can be positioned as the first step. At the third session of the Conference of the Parties (COP3), members agreed on numerical targets that “developed countries reduce their collective greenhouse gases by 5.2% compared to 1990 levels by the period 2008-2012.”

In order to achieve the 6% reduction imposed on Japan, it is necessary to clarify what serious measures the construction industry must take. In response to the Kyoto Protocol, the Architectural Institute of Japan announced in December 1997 that “for future buildings in Japan, we will aim to reduce the life cycle carbon dioxide emissions by 30% and extend durability by three times to 100 years.” We examined the issue as members of the Global Environment Committee.

The research forecasts buildings-related CO₂ emissions up to 2050, classified by various scenarios based on the following analysis:
1) Japan’s future population projections
2) Total floor area per person, on the assumption it will be equivalent to floor areas found in Western Europe and the United States
3) The realities of building durability
4) The cycle of repair work
5) The unit CO₂ emission during use of the building
6) The unit CO₂ emission at the time of construction, based on the input and output table analysis
7) Changes in the unit CO₂ emission from electricity

2. Method of Estimating Buildings-related CO₂ Emissions
2.1 Estimate of Floor Area of New Construction and Renovation Works for Each Year
For basic data to forecast the future, a population projection (prepared by the Ministry of Health and
Welfare) shown in Table 1 indicates that the population will begin to decline after 2010. There exists no comprehensive official data for the total floor area of buildings. For that reason, regarding data before 1995, an estimate is made based on records such as the price of fixed assets, circumstantial analysis of public facilities, and estimated data from Japan’s Institute of Energy Economics shown in Table 1. Also, the future total floor area per person classified by building use and structure has been fixed, as shown in Table 2, assuming it will settle at European levels by around 2010. (Housing area in France, Great Britain, and Germany is 37-38 square meters per person.)

Floor area of new construction classified by use and structure for each year before 1995 is estimated based on the planned area for building starts, construction work execution ratio, and the average construction period on a completion basis in an annual report of building statistics. The forecast is calculated by the following process:

1) It is presumed that completed buildings for each year decrease in accordance with the residual ratio curve shown in Table 3.
2) The area of new construction work for each year was estimated by calculating the building floor area that has to be completed so as to achieve the total building floor area for each year, which is calculated by multiplying Table 2 and Table 3.
3) For the area of renovation work, assuming that some work is made on a 20-year cycle after completion of the building, the floor area of the entire building was estimated.

2.2. Establishing the Unit CO2 Emission

2.2.1. Unit CO2 Emission in New Construction and Renovation Works

The unit CO2 emission in new construction has been fixed as shown in Table 2, by using the 1990 input and output table. This includes not only emissions from the production of building materials, distribution, and construction but also emissions from all domestic industries related to these activities. This basic unit however does not include the pervasive effect overseas, but does include fixed capital formation. In order to reflect periodic changes in the unit CO2 emission from electricity in new construction to estimate results, we calculated the unit CO2 emission of the pervasive effect on the power supply industry using the input and output table. The figures found are shown in brackets in Table 2. The unit CO2 emission for repair work is then calculated from the items of the unit CO2 emission of new construction work calculated by the input and output analysis.

2.2.2. Unit CO2 Emission in Using Houses and Non-housing Construction

For CO2 emissions in using houses and non-housing construction built before 1994, figures for people’s livelihood estimated by the Environment Agency have been adopted, taking conformity with other estimates of CO2 emissions into account. These figures are an aggregate of direct CO2 emissions generated from fuel consumption in the people’s livelihood sector and CO2...
emissions produced by the energy conversion sector in using electrical power.

The unit CO2 emission in the use of unit floor area in houses built after 1995 is shown in the right-hand corner of Table 2. This is arrived at by dividing the total CO2 emissions generated in the use of homes in 1994 by the total floor area of houses in the same year. The unit CO2 emission for non-housing construction has been set in the same way. Basic unit energy consumption per unit floor area of houses built after 1995 is estimated by multiplying the housing floor area for each year. Energy consumption for non-housing construction has also been estimated by the same method. In order to incorporate estimated results with periodic changes in the unit CO2 emission from electricity consumption in the use of houses and non-housing construction, we calculated the unit CO2 emission from the generation of electricity by analyzing the ratio of CO2 emissions using comprehensive statistical data for 1994. The unit CO2 emission is given in brackets.

2.2.3. Countermeasures Scenario for the Construction Industry

We envision five stages, from Scenario 1 (no countermeasures) to Scenario 5 (radical countermeasures), as shown in Table 3. In Scenario 5, it is assumed that the energy consumption per floor area in the use of buildings will be reduced by 30% in all new construction work, and by 15% in all renovation works after 1998. Also, the durability of new construction will give a life three times longer than existing construction, to approximately 100 years. The scenario also calls for widespread use of eco-materials that produce fewer CO2 emissions when they are produced. This is a scenario to establish safe and appropriate social assets that are suitable for the next generation, before Japan’s economic might diminishes. It corresponds to the Architectural Institute of Japan’s announcement in December 1997: “We aim to reduce the life cycle of carbon dioxide emissions by 30% and extend the lifespan by three times longer in future buildings in Japan.” In addition to such a thorough scenario, mild countermeasures, from Scenario 2 to Scenario 4, are also considered. Architectural designs suited to the climate, the natural features of a construction site, improvements in the heat insulation of exterior walls and windows, improvements in solar shading performance, and the introduction of equipment and systems to enhance sufficient use of energy and natural

Table 1. Estimated Method for Total Floor Area Classified by Use and Structure

| Structure and use       | Data for estimating total floor area classified by use and structure for each year. |
|-------------------------|--------------------------------------------------------------------------------------|
| 1. Wooden houses        | Exclusively residential dwellings, apartment houses, multi-use dwellings, farmers’ houses, silk-raising farmers’ houses, fishermen’s houses listed under the “Records of fixed property assets” (1); wooden houses managed by prefectures and municipalities listed under the “Circumstantial analysis of public facilities” (2). |
| 2. Non-wooden houses    | Non-wooden houses and apartment buildings listed under the “Records of fixed property assets” (1); non-wooden houses managed by prefectures and municipalities listed under the “Circumstantial analysis of public facilities” (2); apartment houses built by the Japan Housing and Urban Development Corporation listed under the “Housing economic data” (3). |
| 3. Wooden non-housing construction | 3a. Office buildings Wooden office buildings and banks listed under the “Records of fixed property assets” (1). |
|                         | 3b. Shops Wooden shops listed under the “Records of fixed property assets” (1). |
|                         | 3c. School facilities 3c. Area calculated by multiplying the total floor area of school buildings and gymnasiums (from kindergartens to universities and professional schools) listed in the “Statistical Outline of Education” (4) by the wooden part ratio established by the “Basic Survey of School Facilities” (5). |
|                         | 3d. Hospitals 3d. Hospitals made of wood listed under “Records of fixed property assets” (1). |
|                         | 3e. Factories and warehouses 3e. Wooden factories, warehouses, go-downs, cattle barns for dairy farming, silkworm nurseries, tobacco drying facilities and small attached warehouses listed under the “Records of fixed property assets” (1). |
|                         | 3f. Others Wooden inns, Japanese restaurants, hotels, theaters, movie theaters, and public baths listed under the “Records of fixed property assets” (1). |
| 4. Non-wooden structures other than dwellings | 4a. Office buildings 3a. deduced from office building floor area listed in the “Energy and Economic Statistical Outline” (5). |
|                         | 4b. Shops 3b. deduced from total floor area of department stores, supermarkets, wholesale and retail stores, and restaurants listed in the “Energy and Economic Statistical Outline” (5). |
|                         | 4c. Schools 3c. deduced from school floor area listed in the “Energy and Economic Statistical Outline” (5). |
|                         | 4d. Hospitals 3d. deduced from hospital floor area listed in the “Energy and Economic Statistical Outline” (5). |
|                         | 4e. Factories and warehouses 4e. Total floor area of non-wooden factories and warehouses, markets, and hydro-electric power plants listed under the “Records of fixed property assets” (1). |
|                         | 4f. Others 3f. deduced from total floor area of hotels, theaters, amusement facilities, and others listed in the “Energy and Economic Statistical Outline” (5). |

1) Records of fixed property assets, including prices: Fixed Property Tax Division, Local Tax Bureau, Ministry of Home Affairs
2) Circumstantial analysis of public facilities: Edited by the Finance Research and Guidance Division, Local Tax Bureau, Ministry of Home Affairs
3) Housing economic data: Compiled under the supervision of the Housing Policy Division, Housing Bureau, Ministry of Construction
4) Statistical Outline of Education: Research and Statistics Planning Division, Minister’s Secretariat, Ministry of Education
5) Basic Survey of School Facilities: Research and Statistics Planning Division, Minister’s Secretariat, Ministry of Education
6) Energy and Economic Statistical Outline: Edited by the Institute of Energy Economics, Japan

JAABE vol.1 no.2 November 2002 Toshiharu Ikaga 151
energy are required for energy conservation. Generally, the unit CO\textsubscript{2} emission from new construction and renovation works will increase. Also, the likelihood of tearing down buildings with a short life could be lowered by the following steps:

1) Securing structural strength so that principal structural parts will not be seriously damaged by earthquakes which might take place over several decades.

2) Allowing latitude on story height, the live load on the floor, and space for equipment for easy renovation work in accordance with the change in function of the building.

3) Integrating buildings into the cityscape, so that residents will want to pass them on to future generations. In general, this helps increase the use of building materials and the unit CO\textsubscript{2} emission in new construction and renovation works. On the other hand, by using eco-materials with less CO\textsubscript{2} emissions at the time of production and distribution, the unit CO\textsubscript{2} emission from new construction and renovation works could be reduced.

Based on these assumptions, the construction industry’s scenario is shown in Table 3. The coefficients in Table 3 indicate the values to be multiplied by the unit CO\textsubscript{2} emission in new construction and renovation works shown in Table 2. Also, other than a scenario that assumes countermeasures will start in 1998, a year after the Kyoto meeting, estimates are made for scenarios assuming these measures will start in 2001 and 2006.

### 2.2.4. Scenario to Reduce Unit CO\textsubscript{2} Emission from Electricity

Efforts to reduce CO\textsubscript{2} by the power supply industry and other industries, including a reduction in the unit CO\textsubscript{2} emission (kg-CO\textsubscript{2}/kWh) from electricity, influence the unit CO\textsubscript{2} emission from new construction and renovation works, and the use of buildings. This presentation discusses only measures to reduce the unit CO\textsubscript{2} emission from electricity, which greatly influences all industries, and is presented in the three scenarios shown in Table 4. One scenario where the unit CO\textsubscript{2} emission from electricity for 2010 has been reduced by 20% compared to 1990 is a supplementary explanation in which voluntary numerical targets of the Federation of Electrical Power Companies are cited. Since the achievement of these numerical targets is unlikely considering the present situation, a scenario with half the numerical targets (a 10% reduction) has also been prepared.

We estimated the figures after 2010. Scenario C, where the unit CO\textsubscript{2} emission is 0.4 in 2050, is equivalent to the case where the electricity component

---

### Table 2. The Unit CO\textsubscript{2} Emission in New Construction Work, Renovation Work and Use of Buildings

| Structure and use          | New construction work (kg-CO\textsubscript{2}/m\textsuperscript{2}) | Renovation work (kg-CO\textsubscript{2}/m\textsuperscript{2}) | Operation of building (kg-CO\textsubscript{2}/a/m\textsuperscript{2}) |
|---------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| Wooden houses             | 300 (78)                                        | 60 (16)                                        | 37.2 (22.3)                                     |
| Non-wooden houses         | 599 (144)                                       | 120 (29)                                       |                                                 |
| Wooden non-housing        | 237 (62)                                        | 41 (12)                                        | 40.6 (23.5)                                     |
| Non-wooden non-housing    | 540 (135)                                       | 108 (27)                                       |                                                 |

Note 1: The unit CO\textsubscript{2} emission including capital formation inside Japan
Note 2: Figures in parenthesis are items for the unit CO\textsubscript{2} emitted from power plants

### Table 3. Establishment of Counter-measure Scenarios by the Construction Industry

| Scenarios by the construction industry | New construction work | Renovation work | Operation of building |
|----------------------------------------|-----------------------|----------------|-----------------------|
| 1. No steps taken                      | 1.00                  | 1.00           | 1.00                  |
| 2.20% energy conservation in new construction work, 10% in renovation work | 1.05                  | 1.10           | 0.80                  |
| 3. In addition to Scenario 2, a threefold increase in durability plus the use of eco-materials | 0.90                  | 0.95           | 0.85                  |
| 4. 30% energy conservation in new construction work, 15% in renovation work | 1.10                  | 1.20           | 0.70                  |
| 5. In addition to Scenario 4, a threefold increase in durability plus the use of eco-materials | 1.00                  | 0.95           | 0.85                  |

Note 1: Adjustment coefficient to be multiplied by the unit CO\textsubscript{2} emission in new construction and renovation works, and the use of the building shown in Table 2.

### Table 4. Scenarios to Reduce the Unit CO\textsubscript{2} Emission from Electricity

|                           | 1990 | 2000 | 2010 | 2030 | 2050 |
|---------------------------|------|------|------|------|------|
| a. 0% reduction compared to 1990 levels | 1.0  | 1.0  | 1.0  | 1.0  | 1.0  |
| b. 10% reduction compared to 1990 levels | 1.0  | 0.9  | 0.9  | 0.8  | 0.7  |
| c. 20% reduction compared to 1990 levels | 1.0  | 0.9  | 0.8  | 0.6  | 0.4  |

Note 1: Relative value (-) where the unit CO\textsubscript{2} emission from electricity in 1990 is set as 1.0.
Note 2: According to the “Environmental Action Plan in the Electrical Industry,” voluntary targets based on domestic efforts to achieve by 2010 include: 1) New nuclear power generation (approximately 20-25 million kW, about 20 power plants), 2) Improving efficiency of electric power equipment, 3) Energy conservation in terms of using electricity.
ratio of thermal power generation has declined from 60% to 30% under the following conditions:
1) Voluntary targets set by the Federation of Electrical Power Companies for 2010 have been achieved.
2) Japan’s total electricity consumption has been reduced by 30% compared to 2010, due to steady progress in energy conservation and durability improvement measures in other fields.

3. Estimated Results of Area for New Construction and Renovation Works
3.1. Cases Where Building Durability has not Changed from the Current Situation
Fig.4 shows new construction floor area for each year, on the assumption that buildings constructed in the future will, just like the current situation, be taken down in accordance with the residual ratio curve shown in Fig.3.
It turned out that new construction work, which amounted to 270 million square meters in Japan in 1990, will drop to around 130 million square meters annually after 2020. Japan’s population will peak in 2010, as shown in Table 1. It is assumed that the architectural assets per person will settle at European levels around 2010 as shown in Table 2. With this, the number of buildings to be built will decline. Meanwhile, the floor area of buildings with renovation work for the exterior, interior, and fixtures amounted to 250 square meters in 1990. Hereafter, although there have been ups and downs reflecting the changes in newly-constructed floor area in the past, and the renovated floor area will increase and reach 350 million square meters annually by 2050. The forecast graph indicates the mean shift over five years.

3.2. Cases Where There is a Threefold Increase in Building Durability
Fig.5 shows the estimated results of the new construction floor area for each year in cases where measures have been taken to ensure that all buildings built after 1998 will have a threefold increase in durability. Expand the residual curve in Fig.3 by three times in the direction of the building age indicator. It is...
estimated that the new construction floor area for each year will steadily decrease; by 2050, the floor area for renovation work will dominate.

Measures for a threefold increase in durability are required from another viewpoint, including the capacity of industrial waste disposal plants and the problems of illegal dumping of construction waste.

Designers and contractors who have made new construction and education and research entities to supply personnel their main aim, need to recognize these realities and reconsider their own organizations immediately. It can be readily imagined that the construction industry will be forced to shift from a new construction-oriented industry to a “soft” industry, placing importance in the future on the management of existing architectural assets. In architectural education as well, it appears that enriched design training for renovation and education for management of architectural assets and environmental management will be required. The result will affect other industries that supply the construction industry with materials and equipment. It is inevitable for Japan, which has continued to grow, to go through this when shifting to a sustainable society.

4. Estimation of CO2 Emissions Related to Construction

4.1. Cases Where No Measures are Taken

Cases where no measures are taken shown in Table 5 are buildings-related CO2 emissions where the construction industry has taken no measures and the unit CO2 emission from electricity remains at 1990 levels (Scenario 1-a in Table 5). This results in average emissions in the five-year period 2008 -2012 being 470 million tons of carbon dioxide annually, a 15% increase (an extra 60 million tons compared to 410 million tons in 1990). This indicates that achieving the greenhouse gas reduction targets laid out in the Kyoto meeting is unlikely if the present situation continues. Also, with Japan’s population decreasing from 2010, the building floor area will rise to European levels and the total floor area of buildings will gradually decline. For that reason, buildings-related CO2 emissions will be reduced by 10% compared to 1990. Under this situation, achieving long-term targets set by the IPCC to reduce global CO2 emissions to 33% of 1990 levels by 2100 is impossible.

4.2. The Case Where Thorough Measures are Taken by the Construction and Power Industries

Fig.7. shows an estimate of buildings-related emissions when thorough measures begun by the construction industry in 1998 and the unit CO2 emission from electricity has been reduced, in accordance with set targets (Scenario 5-c-X). The result is that average buildings-related emissions in the period 2008-2012 are 390 million tons of CO2 annually, a 6% decrease of 20 million tons from 1990. The greenhouse gas reduction target for Japan agreed at the Kyoto meeting was 6% compared to 1990 levels by the period 2008-2012. The items stipulated in the Government’s “Outline for the Promotion of Efforts to Prevent Global Warming,” decided in June 1998, are shown in Table 5. Although the CO2 reduction rate is +/- 0%, there are many vague parts, including -3.7% through the absorption of CO2 by forests, in addition to -2% for innovative technology development and “further efforts made at all levels across the country.”

The results in Fig.7 indicate a scenario that achieves the targets of the Kyoto Protocol even though we have to count on a total of -5.7% as a CO2 emission reduction from the production of energy. Also, buildings-related CO2 emissions for 2050 will be reduced to 40% of 1990 levels. The current CO2 emissions in renewable power supply industry 2010 2050 2010 2050 2010 2050

Table 5. Ratio of Buildings-related CO2 Emissions in 2010 and 2050 Compared to Emissions in 1990

| Scenarios | Countermeasure in building industry | Countermeasures in power supply industry | X. start from 1998 | Y. start from 2001 | Z. start from 2006 |
|-----------|----------------------------------|----------------------------------------|-----------------|-----------------|------------------|
| 1-a       | 1. No steps taken                | Case a. (-0%)                          | 1.15            | 0.90            | 1.15             |
| 2-a       | 2. 20% energy conservation in new construction work, 10% in renovation work | Case a. (-0%)                          | 1.09            | 0.80            | 1.15             |
| 3-a       | 3. In addition to Scenario 2, a threefold increase in durability plus the use of eco-materials | Case a. (-0%)                          | 1.05            | 0.65            | 1.10             |
| 4-a       | 4.30% energy conservation in new construction work, 15% in renovation work | Case a. (-0%)                          | 1.04            | 0.75            | 1.14             |
| 5-a       | 5. In addition to Scenario 4, a threefold increase in durability plus the use of eco-materials | Case a. (-0%)                          | 0.99            | 0.54            | 1.05             |

Note 1: Relative values assuming buildings-related CO2 emissions in 1990 (410 million tons CO2/year) as 1.0
Note 2: Figure for 2010 is a mean value for the period 2008-2012
Note 3: Case a: CO2 emission per kWh in 2010 is the same in 1990, Case b: CO2 emission per kWh in 2010 is reduced by 10% compared with the 1990 level. Case c: CO2 emission per kWh in 2010 is reduced by 20% compared with the 1990 level.
emissions per person in Japan are twice the global average. Even taking into account that further efforts at reduction are required, it is possible to achieve the IPCC’s target of reducing global CO₂ emissions by 33% of 1990 levels by 2100.

4.3 The Case Where Countermeasures by the Construction Industry are Delayed

Table 5 shows the relative figures for buildings-related CO₂ emissions against CO₂ emissions in 1990 in the event that the construction industry delays launching countermeasures. It indicates estimates that result in the reduction of the unit CO₂ emissions from electricity in Scenario C (a 20% reduction in 2010 compared to 1990). If the construction industry takes thorough countermeasures from 1998, right after the Kyoto meeting, (Scenario 5-c-X), buildings-related emissions in 2010 are 0.94 compared to 1990 (a 6% reduction). On the other hand, if countermeasures are taken from 2001 (Scenario 5-c-Y), they turn out to be 0.97 (a 3% reduction). Also, if countermeasures are taken in 2006 (Scenario 5-c-Z), emissions are 1.01 (a 1% increase). As a matter of course, the more delay, the more difficulty in achieving the Kyoto targets.

4.4. The Case Where Reduction Targets for the Unit CO₂ Emission from Electricity Fail to Be Achieved

Table 5 shows the relative value against buildings-related CO₂ emissions in 1990 in the event that reduction targets for the unit CO₂ emission from electricity are not met. The relative value of buildings-related CO₂ emissions in 2010 will be 0.94 (a 6% decrease) under the following conditions:

1) The construction industry launches active steps in 1998.
2) The unit CO₂ emission from electricity is reduced by 20% (Scenario 5-c-X). On the other hand, if the unit CO₂ emission from electricity is reduced only by 10% (Scenario 5-b-X), the relative value of buildings-related CO₂ emissions in 2010 will be 0.99 (a 1% reduction). Furthermore, if the unit CO₂ emission from electricity remains at the same level as 1990 (Scenario 5-a-X), the relative value of buildings-related emissions will be 1.02 (a 2% increase). In this way, it is indicated that not only efforts by the construction industry but also efforts by the electric power industry are vital for achieving the reduction targets in the Kyoto Protocol.

5. Conclusion

Estimates on buildings-related CO₂ emissions up to 2050 were made based on a projection of Japan’s future population, the total building floor area per person, assuming it will increase to Western European and U.S.A. levels, the realities of building durability, the building floor area started each year, the cycle of repair work, the unit CO₂ emission at the time of using the building, the unit CO₂ emission at the time of construction based on the input and output analysis, and changes in the unit CO₂ emission from electricity. The estimated results indicate that mean CO₂ emissions in the period 2008-2012 will increase by 15% compared to emissions from 1990 if the current situation continues.

On the other hand, if steps are taken equivalent to the announcement made by the Architectural Institute of Japan made in December 1997 are incorporated into all new construction and renovation works from 1998 and the unit CO₂ emission from electricity is reduced by 20% in 2010 compared to 1990 in accordance with the targets, it is estimated that buildings-related CO₂ emissions will be reduced by 6% during the period 2008-2012 and by up to 40% by 2050. In addition, estimates of reduction were made classified by the year to start countermeasures and steps taken by the construction and electric power industry. In the future, we plan to make projections up to 2050 regarding resource consumption relating to construction and construction waste.

Acknowledgments

In proceeding with this research in 1997, we obtained invaluable advice from the Global Environment Committee, members of the Architectural Institute of Japan, including Dr. Toshihiko Oota, former chairman, and Prof. Hiroshi Akiyama, the current chairman, and Prof. Toshio Ojima, former president. We would like to thank the project members and members of the Committee for their invaluable advice during our research.

References

1) Ikaga T. 1999. Sustainable Construction of Buildings and Cities, Proceedings of the 14th National Congress for environmental studies: pp.85-92, Jan.1999, Science Council of Japan.
2) Ikaga T., Murakami S., Kato S., and Shiraishi S. 1999. Prediction of CO₂ emission related to construction of our country until 2050, Life Cycle Assessment of Buildings and Cities, Summaries of Technical Papers of Annual Meeting D-1: pp.995-996, Sep.1999, Architectural Institute of Japan.
3) Ikaga T. and Murakami S. 2000. Sustainable community and building industry, Journal of Institute of Industrial Science: pp.20-25, Mar.2000, Institute of Industrial Science, University of Tokyo.
4) Architectural Institute of Japan, 1999. Draft Guidelines for LCA of Buildings, Nov.1999, Tokyo, Maruzen.
5) Akiyama H., Ikaga T. and Kimata N. 1999. Approach to Global Environmental Issues and Architecture, Journal of Architectural Institute of Japan, Vol.114, No.1445: pp.38-50, Oct.1999, Architectural Institute of Japan.
6) Sub-committee on sustainable buildings, 1999. Proposal to Promote Sustainable Buildings, Mar.1999, Architectural Institute of Japan.
7) Public Buildings Association, 1999, Guidelines and Manual for the Planning of Environment-Friendly Government Building Facilities, supervised by the Government Buildings Department, Ministry of Construction: Apr.1999.
8) Kato H. and Komatsu Y. 1986. Research on longevity of wooden residential, Journal of the Architectural Planning and Environmental Engineering, No.363: pp.20-26, 1986, Architectural Institute of Japan.

JAABE vol.1 no.2 November 2002
9) Yashiro T., Kato H., Yoshida T. and Komatsu Y. 1990. Actual longevity of office buildings in Chuo-ku, Tokyo, Journal of the Architectural Planning and Environmental Engineering, No.413, Jul. 1990, Architectural Institute of Japan.

10) National Institute of Population and Social Security Research, 1997. Population Prospect of Japan: Jan. 1997, Health and Welfare Statistics Association.

11) Construction Research Institute, 1954-1998. Annual report of architectural statistics, supervised by Construction Economy Bureau, Ministry of Construction: 1954-1998. Construction Research Institute.

12) Fixed Property Tax Division, Local Tax Bureau, Ministry of Home Affairs, 1976-1998. Records of fixed property assets including prices: 1976-1998, Ministry of Home Affairs.

13) Local Tax Bureau, Ministry of Home Affairs, 1991-1998. Circumstantial analysis of public facilities, 1991-1998, Local Finance Association.

14) Institute of Energy Economics Japan, 1999. Handbook of Energy and Economic Statistics in Japan: Jan. 1999, Energy Conservation Center.

15) Statistics Bureau, Management and Coordination Agency, 1982-1997. Japan Statistical Handbook, 1982-1997, Japanese Statistical Association.

16) Ministry of Education, Culture and Sports, 1979-1998. Handbook of education statistics, 1979-1998, Printing Bureau, Ministry of Finance.

17) Housing Industry Newspaper, 1999. Handbook of residential economic data, supervised by Housing Bureau, Ministry of Construction, Oct. 1999, Housing Industry Newspaper.

18) Management and Coordination Agency, 1994. 1990 Input and output table of Japan, Mar. 1994, Nationwide Statistical Association.

19) Institute of Construction Prices Investigation, 1995. 1990 Input-output table for construction sector analysis, supervised by Construction Economy Bureau, Ministry of Construction, Jan. 1995, Institute of Construction Prices Investigation.

20) Agency of Natural Resources and Energy, 1997. Comprehensive energy statistics, Mar. 1997.

21) Federation of Electric Power Companies, 1999. Environmental Action Plan by the Electric Power Industry, Sep. 1999, Federation of Electric Power Companies.

22) General Planning and Coordination Bureau, Environment Agency, 1992, Handbook of global warming prevention, Sep. 1992, Tokyo, Dai-ichi Hoki Publishing.

23) Kondo M. and Moriguchi Y. 1997. Carbon dioxide emission basic unit by input-output table, Mar. 1997, National Institute for Environmental Studies.

24) Environment Agency, 1994. Japan report based on the United Nations Framework for Climate Change, Dec.1994, Printing Bureau, Ministry of Finance.

25) Environment Agency, 1998, The 2nd Japan report based on the United Nations Framework for Climate Change, May 1998, Printing Bureau, Ministry of Finance.

26) Headquarters of Promotion for Global Warming Prevention, 1998.