Chapter 4

Methodology of Applying Control Science to Sustainable Housing Design

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Additional information is available at the end of the chapter

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Abstract

The previous chapter has demonstrated the "basic control system for sustainability", "model of sustainability", and "two-step preparatory work for sustainable design". Based on these basic schemes, this chapter shows the methodology of applying control science to sustainable home design. First, using two factors, that is, "material" and "space", we identify important elements of home. Next, we provide the two-step preparatory work for sustainable home design, namely, (1) determining the relationships between the standard home and sustainability and (2) sustainability checkup on a home as an object. After that, we derive "sustainable design guidelines" from step 1 and "sustainability checklist" from step 2, respectively. Finally, we compose the "control system for promoting sustainable home design" in which the sustainable design guidelines and sustainability checklist are incorporated. This practical control system demonstrates sustainable design processes for both new and existing homes.

Keywords: control system, material elements, spatial elements, sustainable design guidelines, sustainability checklist

1. Introduction

Chapter 3 has shown the "basic control system for sustainability," "model of sustainability," and "two-step preparatory work for sustainable design." Utilizing these basic schemes, this chapter demonstrates the methodology of applying control science to sustainable home design. This methodology is aimed to help not only promote sustainable design but also design sustainable homes.

The methodology is illustrated in the following two sections. The next section shows two-step preparatory work for sustainable home design. Utilizing these two steps, Section 3, which is short but significant, demonstrates the control system for promoting sustainable home design.

2. Two-step preparatory work for sustainable home design

As shown in the previous chapter, the preparatory work for sustainable design consists of the two steps: (1) determining the relationships between the standard human activities and sustainability and (2) sustainability checkup on human activities as an object. When the "home" is identified as a category of human activities, the two steps are (1) "determining the relationships between the standard home and sustainability" and (2) "sustainability checkup on a home as an object."

2.1. Determining the relationships between the standard home and sustainability

The first step aims to select important elements of the standard home and comprehensively determine the relationships between the selected elements and sustainability [1, 2].

In order to efficiently select important elements, we have examined two main factors, namely, "material" and "space" (**Table 1**) [1]. "Material" considers home as the aggregate of material elements, including framework, exterior, interior, and piping. "Space" regards home as the aggregate of spatial elements, including rooms and areas [1]. On the basis of these two factors, we have selected important elements, as shown in the left column of **Table 2**. "Material elements" are from "framework" to "outdoor facilities"; "spatial elements" are from "total floor" to "garden area."

We have subsequently determined the relationships between these elements and internal stability and fundamental stability (**Table 2**). That is to say, examining the relationships between each element and the stability conditions, we have identified variables that indicate the degree of stability [1, 2]. Moreover, we have set these variables' desired values that can satisfy relevant stability conditions [1, 2].

In addition, **Table 2** is the first updated version, which has been revised because of several reasons. First, we have revised the table so that following it leads to long-life quality housing (LQH, *Choki Yuryo Jutaku*) certification. The LQH certification began in 2009, and after that it has rapidly spread in Japan due to a variety of incentives, including tax reduction [3]. The second reason is the addition of adaptation measures against impacts resulting from climate change. Moreover, we have taken accessible and universal design more extensively, adding several spatial elements, such as stairs, hallway, and main access route to the entrance. Other reasons are wide spread of new energy-saving technology, namely, LED light, and minor changes in desired values and expressions.

Factor	Examples of elements (details)
Material	• Framework (pillar, beam, etc.) • Exterior (outer wall, roof, etc.) • Interior (floor, inner wall, ceiling, etc.) • Piping (water pipe, drainage pipe, gas pipe, etc.)
Space	• Room (living room, bedroom, dining room, kitchen, bathroom, etc.) • Area (exterior area, garden area, etc.)

Table 1. Two factors on selecting important elements of home [1].

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Element	Variable	Desired value	Stability condition
Framework	Resistance to earthquakes	JHPIS 1.1: Grade 2 or over	• Safety
	Durability	JHPIS 3.1: Grade 3	• Sustainable resources
	Materials	CASBEE LR_H2 1.1: Level 4 or over	• Sustainable resources
Exterior (outer wall, roof, etc.)	Fire resistance (outer wall)	JHPIS 2.6: Grade 3 or over	• Safety
	Shape and color	Consideration for the landscape	• Health
	Durability	CASBEE Q_H2 1.2 and 1.3: Level 4 or over	• Sustainable resources
	Materials	CASBEE LR_H2 1.3: Level 4 or over	• Sustainable resources
Thermal insulation	Thermal insulation performance	JHPIS 5.1: Grade 4	• Health • Enviro-preservation • Sustainable resources
Windows and doors	Thermal insulation performance	JHPIS 5.1: Grade 4	• Health • Enviro-preservation • Sustainable resources
	Sunlight adjustment capability	CASBEE Q_H1 1.1.2: Level 4 or over	• Health • Enviro-preservation • Sustainable resources
	Sound insulation performance	CASBEE Q_H1 4: Level 4 or over	• Health
	Measures to prevent intrusions	CASBEE Q_H1 2.3: Level 4 or over	• Safety
	Protection of glass against impacts	With shutters	• Safety
Interior	Measures against formaldehyde	CASBEE Q_H1 2.1: Level 5	• Health
	Materials	CASBEE LR_H2 1.4: Level 4 or over	• Sustainable resources
Bathtub	Heat insulation	Insulated	• Enviro-preservation
Piping	Measures for maintenance	JHPIS 4.1: Grade 3	• Sustainable resources
	Method of water and hot-water piping	Header and pipe-in-pipe system	• Enviro-preservation • Sustainable resources
Water heater	Type of water heater	CASBEE LR_H1 2.2.1: Level 5	• Enviro-preservation • Sustainable resources
Appliances	Energy-saving standard achievement rate	100% or more (three or more stars)	• Enviro-preservation • Sustainable resources
Lighting fixtures	Type of light	LED	• Enviro-preservation • Sustainable resources
Equipment for harnessing natural energy	Harnessed natural energy	100% or more of the total energy usage	• Health (in crises) • Safety (in crises) • Enviro-preservation • Sustainable resources
Equipment for rainwater use	Rainwater equipment	CASBEE LR_H1 3.2: Level 4 or over	• Health (in crises) • Safety (in crises) • Enviro-preservation • Sustainable resources

Element	Variable	Desired value	Stability condition
Water-using equipment	Water-saving functions	CASBEE LR_H1 3.1: Level 4 or over	• Enviro-preservation • Sustainable resources
Outdoor facilities (fence, etc.)	Form	Not blocking sightlines	• Safety • Mutual help
	Appearance	Consideration for the landscape	• Health
	Materials	CASBEE LR_H2 1.5: Level 5	• Sustainable resources
Total floor	Total floor area	$75m^2$ or more [Note 3]	• Health
Specified bedroom	Routes to toilet and bath area, dining room, kitchen, and entrance	Accessible without steps	• Health • Safety
	Internal floor space	9 m^2 or more	
Areas relating to water use and hot-water supply	Areas in the home	Placing them closer	• Enviro-preservation • Sustainable resources
Position and area of windows	Natural ventilation	CASBEE Q_H1 1.2.1: Level 5	• Health • Enviro-preservation • Sustainable resources
	Ratio of total window area to floor area in each living space	20% or more	
Toilet	Internal length or spacing	JHPIS 9.1: Grade 3 or over	• Health • Safety
	Handrails which help users sit and stand	Installed	
Bathroom	Floor space and width	JHPIS 9.1: Grade 3 or over	• Health • Safety
	Handrails help users go in and out of the bathtub	Installed	
Stairs	Grade of steepness	JHPIS 9.1: Grade 3 or over	• Health • Safety
	Handrails	Installed	
Doorways	Differences in level	No differences	• Health • Safety
	Width	75 cm or more (bath, 60 cm or more)	
Hallway	Width	78 cm or more (pinch points, 75 cm or more)	• Health • Safety
Main access route to the entrance	Surface	Level or sloping	• Health • Safety
	Width	90 cm or more	
Slope	Grade of steepness	1/8 or less	• Health • Safety
	Handrails	Installed	
Garden area	Ratio of the garden area to the exterior area	40% or more	• Enviro-preservation

[Notes] (1) JHPIS stands for the *Japan Housing Performance Indication Standards* (*for new homes*); (2) CASBEE stands for *CASBEE for Detached Houses* (*New Construction*) – *Technical Manual 2010 Edition*; (3) At least one story's area (excluding stairs) is 40 m^2 or more.

Table 2. Relationships between the standard home and sustainability.

The rest of this section concisely describes the relationships between each material or spatial element and sustainability, in order from the top of **Table 2**.

2.1.1. Material elements

- Framework

Considering the relationship between "framework" and "safety," a condition of internal stability, we have selected "resistance to earthquakes" as a variable and set its desired value at "Grade 2 or over" in the "seismic resistance grades (prevention of collapse of building structures)" of JHPIS, that is, the Japan Housing Performance Indication Standards (for new homes) [4]. The LQH certification requires satisfying "Grade 2 or over" likewise [5]. "Grade 2" means that the building can withstand 1.25 times the strength of an earthquake stipulated in the Building Standards Act of Japan [4]. In Japan, the strength of framework against earthquakes is regarded as extremely important since Japan is a major quake-prone country.

Furthermore, in areas of strong wind or heavy snowfall, "resistance to wind" or "resistance to snow load" needs to be included as a variable, although both of which are excluded from the table.

On the other hand, examining the relationship between "framework" and a condition for fundamental stability, namely, "sustainable use of natural resources," we have identified "durability" and "materials" as variables [2]. Moreover, we have set the desired value of "durability" at "Grade 3" in the "Deterioration resistance grades (Building frames, etc.)" of JHPIS [2]. "Grade 3" requires measures to extend the period of time between the construction and the first large-scale renovation up to three generations (about 75–90 years) or more, under normally assumed natural conditions and maintenance [4]. The LQH certification also requires securing this target grade [5].

Meanwhile, we have set the desired value of "materials" at "Level 4 or over" in the assessment levels of the "Use of resource-saving materials and less waste-producing materials" of CASBEE, namely, *CASBEE for Detached Houses* (*New Construction*) – *Technical Manual 2010 Edition* [2]. In the case of a wooden house, for example, "Level 4" requires that wood from sustainable forests is used for more than half of the building frames [6].

- Exterior (outer wall, roof, etc.)

As for "exterior," which includes roofs and outer walls, we have identified "fire resistance" and "shape and color" as variables relating to internal stability. The desired value of outer walls' "fire resistance" has been set at "Grade 3" in the "fire resistance grades" of JHPIS. "Grade 3" requires that flames are blocked for 45 min or more [4]. Meanwhile, the "shape and color" of the exterior requires "consideration for the landscape" as its desired value, so as to improve scenery or facilitate harmony with the surrounding landscape.

On the other hand, we have selected "durability" and "materials" as variables relating to fundamental stability. The desired value of "durability" is set at "Level 4 or over" in the assessment levels of the "Exterior wall materials" and "Roofing materials" of CASBEE. "Level 4" requires that a service life of 50 years to less than 100 years can be expected [6]. In the case of a service life of less than 50 years, however, the assessment levels can be raised if “ease of replacement” or “deterioration mitigation treatment” is considered [6]. Meanwhile, the desired value of “materials” is set at “Level 4 or over” in the assessment levels of the “Exterior materials” of CASBEE. “Level 4 or over” requires higher-level efforts in utilization of materials which promote resource saving or waste prevention such as recycled, renewable, and recyclable materials [6].

- Thermal insulation

We have identified “thermal insulation performance” as the variable of “thermal insulation” and set its desired value at “Grade 4” in the “Energy-saving action grades (Thermal insulation performance grades)” of JHPIS, which is the highest in the grades [4]. “Grade 4” requires that measures are taken to reduce energy use to a significant degree [4], details of which are shown in the *Judgement Criteria on Improvement in Housing Energy Efficiency for Building Owners*. According to this judgment, thermal insulation performance of the building was mainly evaluated, based on “thermal loss coefficient (Q)” (**Table 3**). The standard value of “Q” varies, depending on climate classification; for example, that of the classified area where it is relatively warm (including Tokyo) has been set at “2.7 $W/(m^2 * K)$ or less” [7]. Recently, this judgment criterion has been revised into the new version. According to the current judgment criteria, thermal insulation performance is evaluated on the basis of “building envelope’s average heat transmission coefficient (U_A)” (**Table 3**). The criterion of “U_A” for the area where Tokyo is included has been set at “0.87 $W/(m^2 * K)$ or less” [8]. In addition, the *Guidelines for Design, Construction, and Maintenance on Improvement in Housing Energy Efficiency* show details of the criteria, including standard values by building parts or construction materials as well as technical guidelines for meeting the criteria [9].

“Thermal insulation performance” is important because it is related to both internal stability and fundamental stability. An increase in thermal insulation performance contributes to the sustainable use of natural resources and environmental preservation through a reduction in energy usage for heating and air-conditioning.

Meanwhile, there have been many studies which show correlation between higher thermal insulation performance and residents’ better health. For example, empirical research in New Zealand has demonstrated that insulating existing homes led to significant improvements in

	Main housing thermal performance criterion stipulated in the judgment criteria for building owners	**Standard value in Tokyo area**
Former criterion	Thermal loss coefficient of the building (Q) $Q\,[W/(m^2 K)] = \frac{\text{thermal loss from the building}}{\text{(total floor area)} \times \text{(temperature difference unit)}}$	$Q = 2.7\,[W/(m^2 K)]$ or less
Current criterion (2013~)	Building envelope’s average heat transmission coefficient (U_A) $U_A[W/(m^2 K)] = \frac{\text{thermal loss from the building}}{\text{(total area of building envelope)} \times \text{(temperature difference unit)}}$	$U_A = 0.87\,[W/(m^2 K)]$ or less

Table 3. Main housing thermal performance criteria stipulated in the judgment criteria for building owners of Japan.

the residents' self-reported health and in taking days off from school and work [10]. Similarly, research in Japan has shown that upgrading of thermal insulation performance decreased the occupants' prevalence rates of various diseases, such as allergic rhinitis, bronchial asthma, atopic dermatitis, and heart diseases [11]. Furthermore, a recent survey in Japan has indicated that improvement in thermal insulation performance increases indoor temperature in winter and reduces the occupants' blood pressure [12]. Reduction of blood pressure leads to decrease in the risk of heart attack and stroke.

- Windows and doors

We have selected five items as the variables of "windows and doors," that is, thermal insulation performance, sunlight adjustment capability, sound insulation performance, measures to prevent intrusions, and protection of glass against impacts.

Higher "thermal insulation performance" of openings is essential for stable indoor temperature and energy conservation. The ratio of heat flow through openings including windows is much larger than other parts such as walls and floors. According to an analysis in Japan, heat flow through openings accounts for more than half of the total heat flow: 58% of the total outflow while heating in the winter and 73% of the total inflow while air-conditioning in the summer [13]. As described in the above section of "thermal insulation," higher thermal insulation performance helps occupants' better health, as well as environmental preservation and sustainable use of natural resources. We have set the desired value at the highest "Grade 4" of the "energy-action grades (thermal insulation performance grades)" of JHPIS.

"Sunlight adjustment capability" evaluates the design of windows that blocks solar radiation during summer and captures it during winter, based on the sunlight penetration ratio. Higher sunlight adjustment capability also contributes to residents' better health, in addition to fundamental stability. The desired value is set at "Level 4 or over" of the relevant item of CASBEE. "Level 4" requires that the building can reduce the sunlight penetration ratio in the subject windows to 0.45 or less in the summer. "Level 5," the highest level, requires reducing it to 0.3 or less in the summer and 0.6 or more in the winter [6]. The factors that have influence on the sunlight penetration ratio are (a) type of glass, (b) solar shading materials such as lace curtains and blinds, and (c) eaves [6]. In addition, deciduous trees that create shade over almost the entire surface of the target window during the summer can be in the calculation as a factor of solar shading equivalent to eaves [6]. In this way, in order to meet sunlight adjustment capability, related elements such as curtains, blinds, eaves, and even trees are often required to work together.

Higher "sound insulation performance" of windows and doors is essential for indoor quietness against outdoor noise. The desired value of this variable has been set at "Level 4 or over" of the "Quietness" of CASBEE. "Level 4" and "Level 5" of the "Quietness" correspond to "Grade 2" and "Grade 3" of the "Transmission loss grades (Exterior wall openings)" of JHPIS, respectively [6]. "Grade 2" requires "equal to or higher than Rm (1/3) – 20db," which means 20db or more of sound transmission loss, measured by one-third octave band analysis. Similarly, "Grade 3" requires "equal to or higher than Rm (1/3) – 25db" [4].

Considering the relationship with safety, we have identified “measures to prevent intrusions” as a variable and set its desired value at “Level 4 or over” in the assessment levels of the “Precautions against crime” of CASBEE. “Level 4” requires that, regarding openings whose sizes have a risk of intrusion, effective measures to prevent intrusion have been taken for the entrance to the building and other openings whose lower edge is 2 m or less from ground level [6]. In the above explanation, “effective measures” include the installation of two or more locks in different places and attachment of covers such as shutters [6].

According to the IPCC, climate change is projected to increase impacts from extreme weather events, such as heat waves, droughts, floods, cyclones, and wildfires. A first step toward adaptation to future climate change is reducing vulnerability and exposure to present climate variability [14]. Therefore, it must be significant to protect the most vulnerable part of housing exterior, that is, window glass. Based on the above recognition, we have added “protection of glass against impacts” as a variable and set its desired value as “with shutters.” Shutters are expected to reduce risks from fires, typhoons, tornadoes, and flying objects. In addition, *Your Home: Australia’s guide to environmentally sustainable homes* also recommends installation of window protection like shutters, as an adaptation strategy to prepare against impacts such as bushfires, cyclones, and thunderstorms [15].

- Interior

“Interior,” which includes floors, inner walls, and ceilings, requires “measures against formaldehyde” and “materials” as its variables.

Considering the relationship with “health,” a condition of internal stability, we have identified “measures against formaldehyde” as a variable of interior. Formaldehyde is a colorless, flammable gas at room temperature and has a strong odor [16]. Formaldehyde is used in making building materials and many household products; for example, it is found in pressed-wood products, glues, permanent press fabrics, paper product coatings, and certain insulation materials [16]. Exposure to formaldehyde can cause adverse health effects, such as irritation of the skin, eyes, nose, and throat; high levels of exposure may cause some types of cancers [16]. We have set the desired value of “measures against formaldehyde” at “Level 5” of the “Countermeasures against chemical contaminants” of CASBEE. “Level 5” is equivalent to “Grade 3” in the section of the JHPIS’s “Countermeasures against formaldehyde (Interior, ceiling plenum, etc.)” [6]. “Grade 3,” the highest grade, means that formaldehyde emissions from interior finish and base materials are “extremely low.” This requires the use of “F-four-star” certified products, which are the top-rated products in the formaldehyde emission standards according to the Japanese Industrial Standards and Japanese Agricultural Standards [4, 6].

On the other hand, we have set the desired value of “materials” as “Level 4 or over” of the CASBEE’s relevant assessment item, “Interior materials.” “Level 4 or over” requires higher-level efforts in utilization of materials which promote resource saving or waste prevention such as recycled, renewable, and recyclable materials [6].

- Bathtub

We have attached importance to “heat insulation” as a variable of the “bathtub” since “insulated” bathtubs can reduce heat loss of the hot water. This consideration is necessary because of a Japanese lifestyle; people frequently take a bath and usually share the same hot water in the bathtub with their family members.

- Piping

"Piping," including drainage pipes, water pipes, hot-water pipes, and gas pipes, needs "measures for maintenance" as an important variable toward a long service life. The desired value of the variable has been set at "Grade 3" of the "Maintenance grades" of JHPIS. Grade 3 requires consideration for making maintenance easier, such as not burying piping under concrete and creating openings for cleaning and inspection [4].

In addition, we have selected "method of water and hot-water piping" as another variable of piping and set its desired value at the "header and pipe-in-pipe system." In this piping system, water supply and hot-water supply branch into water pipes and hot-water pipes at the header, as shown in **Figure 1(A)**. Each water pipe or hot-water pipe connects the header and each faucet without any joints. Meanwhile, the pipes used in this system have double-tube structure. The outer plastic pipes play a role of guide and protection of the inner plastic pipes, which are usually made of cross-linked polyethylene [17].

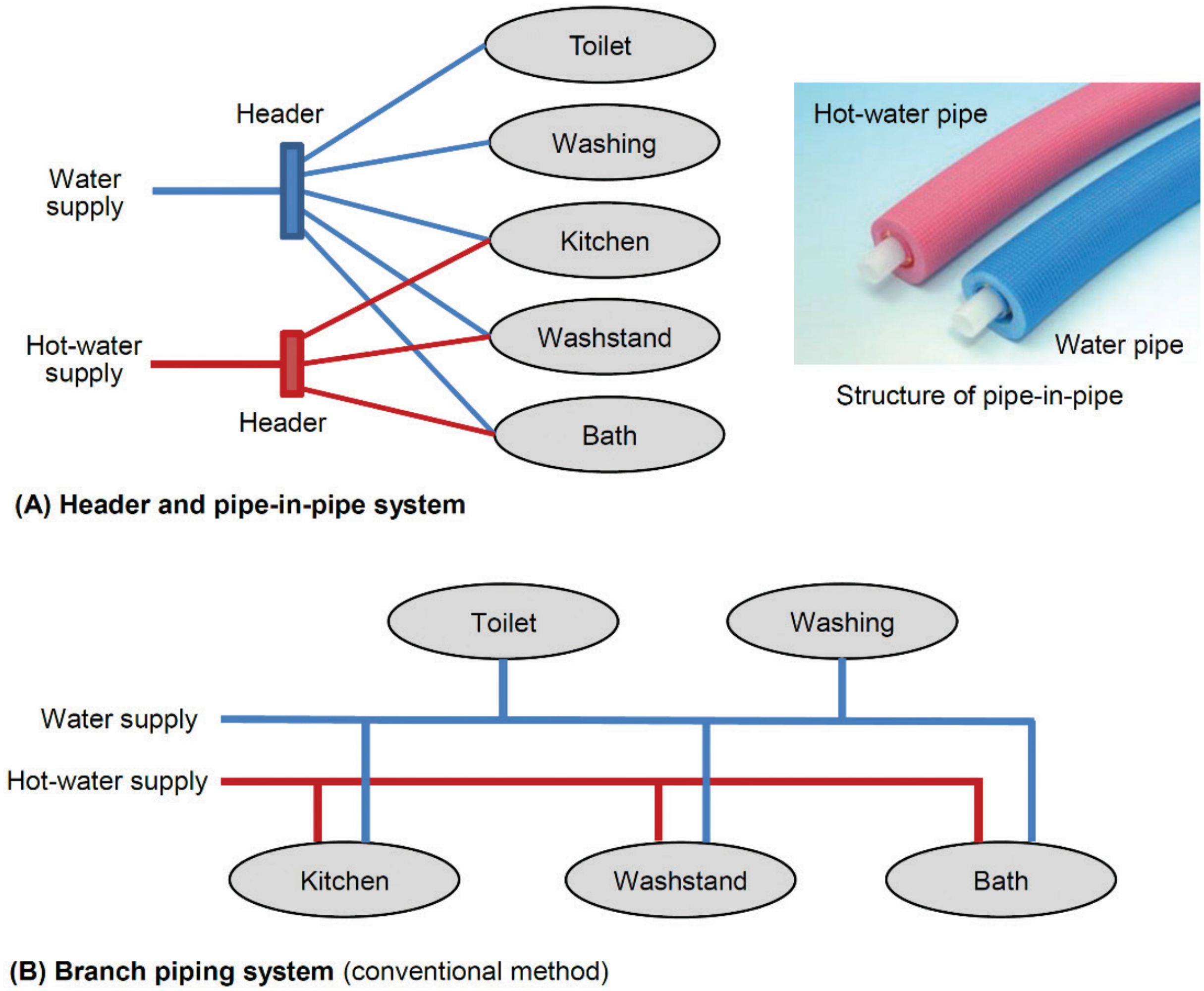

Figure 1. Header and pipe-in-pipe system and branch piping system.

As compared with the conventional "branch piping system," the schematic depiction of which is demonstrated in **Figure 1(B)**, the "header and pipe-in-pipe system" has various advantages. First, this system is superior in durability and maintenance due to the following reasons: (1) unlike conventional metal pipes, plastic pipes do not corrode, and (2) replacement of the inner pipes is easy because both inner and outer pipes are flexible and jointless between the header and each faucet [17, 18]. Second, this piping system is more energy saving since the diameter of the hot-water pipes is normally smaller than that in the branching system, and therefore the wastage of hot water can be reduced [6]. In addition, the piping work of this system is easier than the conventional method, and the installation time can be reduced [17, 18]. Furthermore, the flow of water or hot water is stable even if more than two faucets are used at the same time [17, 18]. As a result of these advantages, this "header and pipe-in-pipe system" has been becoming widespread in Japan since around 1990 [17, 18].

- Water heater

We have identified "type of water heater" as a key variable of the "water heater." The desired value of the type of water heater has been set at "Level 5," the highest level, in the hot-water supply equipment assessment levels of CASBEE. This level includes most energy-efficient types of water heaters, that is, (1) fuel burning, latent-heat recovery, instant-supply-type water heater, (2) electric heat-pump water heater, (3) solar water heater, and (4) solar hot-water supply system [6].

- Appliances

Home appliances are necessary to be energy-saving devices. We have identified the variable of such appliances as "energy-saving standard achievement rate" and set its desired value at "100% or more," in principle.

As demonstrated in **Figure 2**, an energy-saving standard achievement rate is displayed on "energy-saving labels," with the green or orange mark and approximately annual electricity consumption. The green mark is the symbol of achievement, which means the product's energy-saving standard achievement rate is 100% or more. The orange mark is the symbol of nonachievement, which means the rate is less than 100% [19]. In addition, the standard of energy-saving standard achievement rate is determined, based on the energy-saving level of the most energy-efficient products in each appliance [20].

Meanwhile, "unified energy-saving labels," an example of which is shown in the right of **Figure 2**, are used for several kinds of electrical appliances. On a unified energy-saving label, the energy-saving rating of the product is largely displayed, on a scale of one to five stars. In the case of appliances subject to unified energy-saving labels, we have set "three or more stars" as the desired value, following the manual of CASBEE for Detached Houses [6]. In addition, the target appliances of unified energy-saving labels include air-conditioners, refrigerators, televisions, and electric toilet seats. These electrical appliances consume much energy, and there are large differences in energy-saving performance

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between products; therefore, they have been selected as the target appliances of the unified energy-saving label [21].

- Lighting fixtures

We have identified the variable of "lighting fixtures" as "type of light" and set its desire value at "LED." Main reasons why this revised version has restricted only LED lights and excluded fluorescent lights are as follows: (1) superior energy-saving efficiency, (2) significantly longer lifespan, and (3) recent price reduction and rapid spread of LED technology [22].

- Equipment for harnessing natural energy

We have identified "harnessed natural energy" as the variable of "equipment for harnessing natural energy" such as solar panels and set at "100% or more of the total energy usage" as its desired value. This desired value means achieving net zero energy or energy plus housing. In addition to environmental preservation and sustainable use of natural resources, equipment for harnessing natural energy also contributes to health and safety in crises by generating emergency energy.

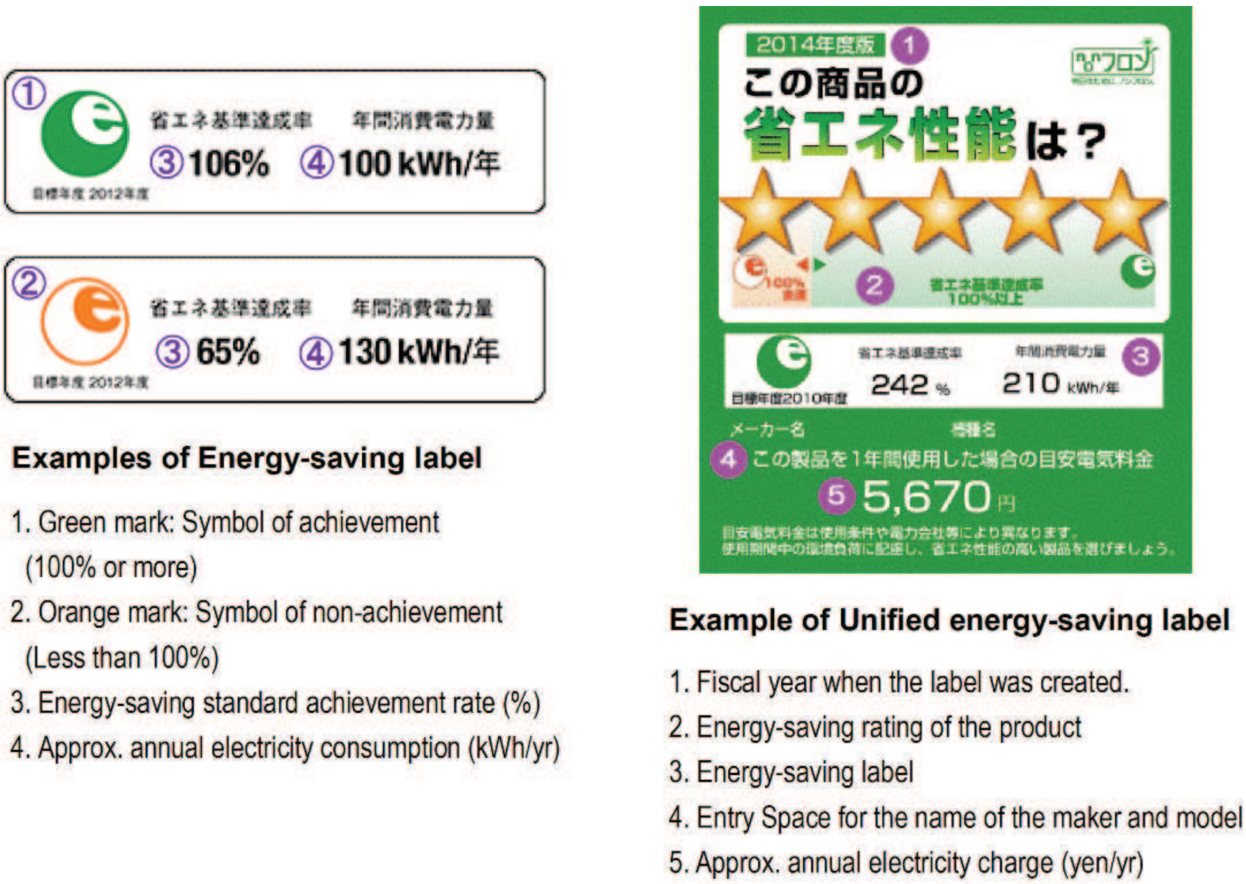

Figure 2. Examples of energy-saving label and unified energy-saving label [19].

- Equipment for rainwater use

If “equipment for rainwater use” is installed, it can reduce the quantity of water supply and contributes to fundamental stability. Reducing water supply leads to energy conservation and reductions in CO_2 emissions because energy is consumed through the process of water purification and distribution. Moreover, storing rainwater also contributes to health and safety in crises, by securing emergency water.

We have identified “rainwater equipment” as the variable and “Level 4 or over” of the CASBEE’s relevant item as its desired value. “Level 4” requires installing a rainwater tank with a capacity of 80 liters or more. “Level 5” requires installing a rainwater utilization system with a cleaning water function for indoor use such as toilet flushing [6].

- Water-using equipment

“Water-using equipment,” including toilet bowls, faucets, and shower heads, requires “water-saving functions” as its key variable. The desired value of this variable has been set at “Level 4 or over” of the CASBEE’s relevant item, “Water-saving systems.” In order to satisfy this desired value, home designers must adopt two or more water-saving efforts from the following five efforts: (1) water-saving-type toilets, (2) kitchen water-saving-type faucets, (3) bath water-saving-type faucet (4) dish washer, and (5) other water-saving methods [6].

- Outdoor facilities (fence, etc.)

We have selected “form” and “appearance” as variables relating to internal stability. “Form” of outdoor facilities, especially fences and barriers, should be “not blocking sightlines” since good visibility can bring “safety” and “mutual help” through preventing crime and allowing face-to-face communication. Meanwhile, “appearance” of outdoor facilities, such as shape and color, needs “consideration for the landscape,” so as to improve scenery or promote harmony with the surrounding.

On the other hand, considering the relationship between “outdoor facilities” and “sustainable use of natural resources,” we have identified “materials” as a variable and “Level 5” of the relevant item of CASBEE as its desired value. Level 5 requires using any of the following materials: (1) recycled materials, (2) reused materials, (3) wood produced from sustainable forests, and (4) natural materials which quickly become usable such as bamboo [6]. In addition, a note of this section says “recyclable materials” such as aluminum are acceptable, although this is excluded from the list [6].

2.1.2. Spatial elements

- Total floor

We have added “total floor” to the list of spatial elements because the long-life quality housing (LQH) certification requires the satisfactory size of the “total floor area.” To be concrete, the

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LQH certification requires “75m^2 or more” as the criterion of the total floor area of detached houses. The criterion adds the proviso that at least one story’s floor area (excluding stairs) is 40m^2 or more [5]. In addition, “75m^2 or more” is equivalent to the floor area for two-person households of the “general-type target housing floor area level,” which has been provided in the “Basic Plan for Housing (National Plan)” of Japan [6].

- Specified bedroom

A “specified bedroom” means a bedroom which is used or expected to be used by elderly or wheelchair users [23]. “Routes to the toilet, bath, dining room, kitchen and entrance” from the specified bedroom should be “accessible without steps.” Therefore, all of such essential rooms and areas need to be arranged on the same floor, unless the house is equipped with an elevator or a lift.

Moreover, a specified bedroom requires “9 m^2 or more” as its “internal floor space.” We have set this desired value on the basis of “Grade 3” of the JHPIS’s relevant item, “Elderly friendliness grades (Dedicated spaces)” [23].

- Areas relating to water use and hot-water supply

“Areas relating to water use and hot-water supply” means a wet area (kitchen and bathroom area) and the area of a water heater. If such “areas in the home” are placed closer, the total length of water and hot-water piping and drainage piping can be reduced. Moreover, this consideration helps to reduce heat loss from hot-water piping.

- Position and area of windows

When planning “position and area of windows,” we need to consider “natural ventilation” and “daylighting,” both of which relate to fundamental stability and internal stability.

We have set the desired value of “natural ventilation” at “Level 5” of the CASBEE’s relevant item, “Allowing breezes in and heat out.” “Level 5” requires that the house has windows facing two or more directions in all living spaces [6]. Even if there is a window facing one direction, the house may be rated as “Level 5” if it is designed to promote ventilation and heat removal. Such design methods include securing paths for ventilation throughout the house, for example, by using sliding doors or latticed doors [6]. Adequate natural ventilation helps to reduce energy for air-conditioning as well as make the indoor environment more comfortable and healthier.

Meanwhile, we have identified “ratio of total window area to floor area in each living space” as the variable relating to daylighting and set its desired value at “20% or more.” The value “20%” exceeds the legally stipulated value, or 1/7 (14.3%), and is equivalent to the satisfactory level of the relevant assessment item of CASBEE [6]. Taking in daylight through windows gives a sense of spaciousness to the occupants [24]. Moreover, recent studies show that bathing in daylight normalizes our biorhythm and contributes to health, for example, by improving sleep disorder, depression, and cognitive function; for example, see [24, 25]. On the other hand, the use of daylight leads to reducing energy for illumination.

- Toilet

We have selected "internal length or spacing" and "handrails which help users sit and stand" as variables of a "toilet." We have set the desired value of "internal length or spacing" at "Grade 3" of the JHPIS's relevant item, "Elderly friendliness grades (Dedicated spaces)," as the minimum level. "Grade 3" requires to meet either of the following two conditions: (1) at least 130 cm as the internal length of the space or (2) at least 50 cm as a spacing from the front rim or side rim of the toilet bowl [23]. Moreover, "handrails which help users sit and stand" need to be "installed."

- Bathroom

In Japanese homes, a "bathroom" is usually arranged separately from a toilet. Similar to a toilet, we have identified "floor space and width" and "handrails which help users go in and out of the bathtub" as variables of a "bathroom." We have set the desired value of "floor space and width" at "Grade 3" of the JHPIS's relevant item. "Grade 3" requires to satisfy both of the following two criteria: (1) at least 130 cm as the internal width of the space and (2) at least 2.0 m^2 as the internal floor space [23]. Furthermore, "handrails which help users go in and out of the bathtub" are necessary to be "installed."

- Stairs

It is essential to improve the safety of "stairs," in order to prevent accidental falls. We have identified "grade of steepness" and "handrails" as variables of stairs. We have set the desired value of "grade of steepness" at "Grade 3" of the JHPIS's relevant item. "Grade 3" requires to satisfy all of the following three criteria: (1) grade of steepness = rise/run ≤22/21, (2) 550 mm ≤ (rise * 2 + run) ≤ 650 mm, and (3) run ≥195 mm [23]. Meanwhile, "handrails" need to be "installed" at least on one side.

- Doorways

A "doorway" is a space where a door opens and closes. No "differences in level" in doorways allow everyone including elderly, children, and wheelchair users to pass through smoothly. Meanwhile, we have set the desired value of the "width" of doorways at "75 cm or more" and that of a bathroom's doorway at "60 cm or more." These desired values correspond to the standard values provided in "Grade 3" of the JHPIS's relevant item, "Elderly friendliness grades (Dedicated spaces)" [23].

- Hallway

Similar to doorways, we have set the desired value of the "width" of a "hallway" at "78 cm or more." The width of a hallway can be reduced to "75 cm or more" at pinch points such as beside a pillar. These figures are equivalent to the standard values shown in "Grade 3" of the JHPIS's relevant item [23].

- Main access route to the entrance and slope

"Main access route to the entrance" is usually the paths to the entrance from the street and/or car parking space. We have identified "surface" and "width" as the variables of this element. Easy and safe access requires the surface to be "level or sloping." The width of the main access route to the entrance should be "90 cm or more."

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Moreover, a "slope" should also be easy and safe to access. We have identified "grade of steepness" of slopes as a variable and set its desired value at "1/8 or less." The other variable "handrails" should be "installed," unless the slope is sufficiently gentle, namely, 1/20 or less.

In addition, we have added these elements, aiming to take universal design into housing exterior as well as interior. As described in the chapter of "Introduction," universal design principles require homes to "be easy to enter" as well as other features, such as "be easy to move around in" [26]. Foreign universal design guidelines for detached houses include descriptions of dwelling access; to be concrete, both of the *Lifetimes Homes* of the UK and the *Livable Housing Design* of Australia require an access route to the dwelling entrance to be level or gently sloping [27, 28].

Meanwhile, Japanese society appears to be unconcerned or apathetic about the accessibility of pathways to detached houses. In fact, access routes to the entrance of almost all Japanese houses have steps, as shown in **Figure 3**. Moreover, the JHPIS does not describe the accessibility

Figure 3. Main access route to the entrance of common houses in Japan.

of the exterior area of private houses, whereas it provides detailed information on the indoor accessibility. Japanese public housing accessible design guidelines state that access routes to houses should be suitable for walking and using wheelchairs [29]; however, it does not refer to concrete specifications. Nevertheless, I occasionally come across places in which handrails have necessarily been added to the step area (**Figure 3**, upper right) or steps have been converted into a slope after construction (**Figure 3**, lower right). It is obvious that the accessibility of pathways to detached houses is necessary in Japan, the fastest aging country in the world.

When specifying the "main access route to the entrance" and "slope," we have referred to foreign universal design guidelines for detached houses, such as the *Lifetime Homes*, and Japanese universal design guidelines for public and commercial facilities, such as the *Architectural Design Standards for Facilitating Mobility of the Elderly, Handicapped and Others*. Moreover, we have taken the smallness of Japanese housing lots into consideration. The maximum grade of the slope, namely, "1/8," is equivalent to the maximum grade for short slopes, specified in the *Architectural Design Standards for Facilitating Mobility of the Elderly, Handicapped and Others* [30]. The minimum width of the main access route, namely, "90 cm," is equal to the minimum width of relevant routes required in the *Lifetime Homes* of the UK [27].

- Garden area

A "garden area" is an area with plants, including trees, shrubs, grasses, herbs, and vegetables. An area with plants is more environmentally friendly than that covered with concrete or asphalt, due to various reasons, such as a higher level of biodiversity, healthier water cycle, and mitigation of heat island phenomenon.

The variable of a garden area has been identified as "ratio of the garden area to the exterior area," and its desired value has been set at "40% or more." The desired value, 40% or more of the garden area to the exterior area, corresponds to "level 4" in the assessment levels of the "Greening of the premises" of CASBEE [6]. In addition, the garden area includes any planted area not only on the ground but also on the roof.

2.2. Sustainability checkup on a home as an object

The second step is "sustainability checkup on a home as an object." The second step starts with the measurement or estimation of the aforementioned variables of a home as an object [1, 2]. Subsequently, the measured or estimated values are compared with the desired values, and the comparison results are assessed [1, 2]. **Table 4** shows an example of "sustainability checkup on a home as an object," which is equivalent to the results of a checkup on an existing home.

In this case, the checkup results have simply been assessed whether the variable reaches the desired value or not, that is, "OK" or "No." The variables that have been assessed as "No" need to be identified as "controlled variables." In addition, this home is naturally identified as a "controlled object" because it includes controlled variables.

Element	Variable	Measured or estimated value	Assess.	Desired value
Framework	Resistance to earthquakes	JHPIS 1.1: Grade 1	No	JHPIS 1.1: Grade 2 or over
	Durability	JHPIS 3.1: Grade 1	No	JHPIS 3.1: Grade 3
	Materials	CASBEE LR_H2 1.1: Level 4	OK	CASBEE LR_H2 1.1: Level 4 or over
Exterior (outer wall, roof, etc.)	Fire resistance (outer wall)	JHPIS 2.6: Grade 3	OK	JHPIS 2.6: Grade 3 or over
	Shape and color	Consideration for the landscape	OK	Consideration for the landscape
	Durability	CASBEE Q_H2 1.2 and 1.3: Level 2	No	CASBEE Q_H2 1.2 and 1.3: Level 4 or over
	Materials	CASBEE LR_H2 1.3: Level 3	No	CASBEE LR_H2 1.3: Level 4 or over
Thermal insulation	Thermal insulation performance	JHPIS 5.1: Grade 1	No	JHPIS 5.1: Grade 4
Windows and doors	Thermal insulation performance	JHPIS 5.1: Grade 1	No	JHPIS 5.1: Grade 4
	Sunlight adjustment capability	CASBEE Q_H1 1.1.2: Level 3	No	CASBEE Q_H1 1.1.2: Level 4 or over
	Sound insulation performance	CASBEE Q_H1 4: Level 3	No	CASBEE Q_H1 4: Level 4 or over
	Measures to prevent intrusions	CASBEE Q_H1 2.3: Level 3	No	CASBEE Q_H1 2.3: Level 4 or over
	Protection of glass against impacts	With shutters	OK	With shutters
Interior	Measures against formaldehyde	CASBEE Q_H1 2.1: Level 5	OK	CASBEE Q_H1 2.1: Level 5
	Materials	CASBEE LR_H2 1.4: Level 4	OK	CASBEE LR_H2 1.4: Level 4 or over
Bathtub	Heat insulation	Not insulated	No	Insulated
Piping	Measures for maintenance	JHPIS 4.1: Grade 3	OK	JHPIS 4.1: Grade 3
	Method of water and hot-water piping	Branch piping system	No	Header and pipe-in-pipe system
Water heater	Type of water heater	CASBEE LR_H1 2.2.1: Level 1	No	CASBEE LR_H1 2.2.1: Level 5
Appliances	Energy-saving standard achievement rate	70–95%	No	100% or more (three or more stars)
Lighting fixtures	Type of light	Fluorescent	No	LED
Equipment for harnessing natural energy	Harnessed natural energy	0 (zero)	No	100% or more of the total energy usage
Equipment for rainwater use	Rainwater equipment	No equipment	No	CASBEE LR_H1 3.2: Level 4 or over
Water-using equipment	Water-saving functions	CASBEE LR_H1 3.1: Level 1	No	CASBEE LR_H1 3.1: Level 4 or over

Element	Variable	Measured or estimated value	Assess.	Desired value
Outdoor facilities (fence, etc.)	Form	Not blocking sightlines	OK	Not blocking sightlines
	Appearance	Consideration for the landscape	OK	Consideration for the landscape
	Materials	CASBEE LR_H2 1.5: Level 5	OK	CASBEE LR_H2 1.5: Level 5
Total floor	Total floor area	116 m^2	OK	75m^2 or more [Note 4]
Specified bedroom	Routes to toilet and bath area, dining room, kitchen, and entrance	With steps	No	Accessible without steps
	Internal floor space	9.7 m^2	OK	9 m^2 or more
Areas relating to water use and hot-water supply	Areas in the home	Placing them closer	OK	Placing them closer
Position and area of windows	Natural ventilation	CASBEE Q_H1 1.2.1: Level 5	OK	CASBEE Q_H1 1.2.1: Level 5
	Ratio of total window area to floor area in each living space	20–22%	OK	20% or more
Toilet	Internal length or spacing	Internal length: 120 cm Spacing: 55 cm	OK	JHPIS 9.1: Grade 3 or over
	Handrails which help users sit and stand	Installed	OK	Installed
Bathroom	Floor space and width	Floor space: 2.6 m^2 Width: 160 cm	OK	JHPIS 9.1: Grade 3 or over
	Handrails help users go in and out of the bathtub	Not installed	No	Installed
Stairs	Grade of steepness	25/21	No	JHPIS 9.1: Grade 3 or over
	Handrails	Installed	OK	Installed
Doorways	Differences in level	With differences	No	No differences
	Width	60–70 cm	No	75 cm or more (bath, 60 cm or more)
Hallway	Width	78 cm	OK	78 cm or more
Main access route to the entrance	Surface	With steps	No	Level or sloping
	Width	140 cm	OK	90 cm or more
Slope	Grade of steepness	No slope	No	1/8 or less
	Handrails			Installed
Garden area	Ratio of garden area to exterior area	63%	OK	40% or more

(1) JHPIS stands for the *Japan Housing Performance Indication Standards* (*for new homes*). (2) CASBEE stands for *CASBEE for Detached Houses* (*New Construction*): *Technical Manual 2010 Edition*. (3) When this checklist is used for the inspection or evaluation of existing homes, *JHPIS* (*for existing homes*) and *CASBEE for Detached Houses* (*Existing Building*): *Technical Manual 2011 Edition* need to be referred to, instead of the "for new homes" version and "New Construction" version, respectively. (4) At least one story's area (excluding stairs) is 40 m^2 or more.

Table 4. An example of sustainability checkup on a home as an object.

Here I view the checkup results, choosing several elements from **Table 4**. Concerning "framework," two of the three variables, "resistance to earthquakes" and "durability," have been assessed as "No," because they are lower than the desired values. "Protection of glass against impacts," a variable of "windows and doors," has been assessed as "OK" since almost all windows of this home are equipped "with shutters." The "type" of the "water heater" used in this home is an energy-wasteful gas heater. As a result, it has been estimated at Level 1 of the relevant item of CASBEE and hence assessed as "No." "Areas in the home," the variable of "areas relating to water use and hot-water supply," has been assessed as "OK" because such areas are placed closer in this house. "Surface," a variable of "main access route to the entrance," is "with steps;" therefore, it has been assessed as "No."

3. Control system for promoting sustainable home design

Utilizing the "basic control system for sustainability" and the "two-step preparatory work for sustainable home design," we have produced the "control system for promoting sustainable home design" [2].

First of all, as demonstrated in **Figure 4**, we have derived two practical functions from the two-step preparatory work, namely, the "sustainable design guidelines" from Step 1 and the "sustainability checklist" from Step 2, respectively [2].

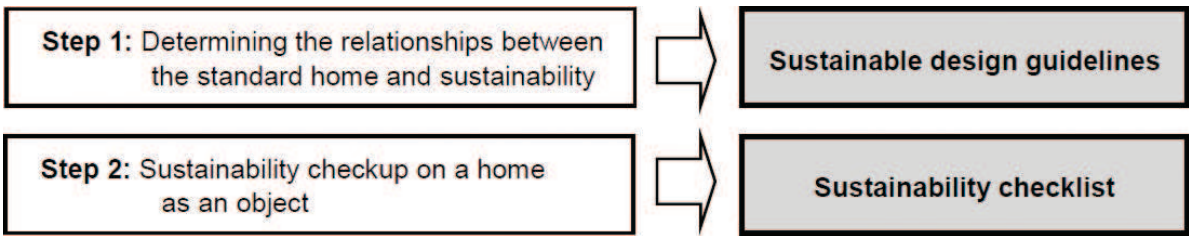

Figure 4. Two practical functions derived from the two-step preparatory work [2].

After that, we have formed the "control system for promoting sustainable home design" in which these two practical functions are incorporated [2]. **Figure 5** shows the block diagram of that control system. In this control system, "people involved in design" include homeowners, architects, designers, and homebuilders [2]. "Controlled objects" are both "new homes" and "existing homes" [2]. The following illustrates how to use the guidelines and checklist in the process of sustainable housing design, in the order of "new homes" and "existing homes."

3.1. New homes

When objects are new homes, first, information on the desired values reaches "people involved in design" through the "sustainable design guidelines" [2]. People involved make "drawings and specifications," so that the variables of home's elements can attain their desired values as much as possible [2]. At important steps in the design process, people involved in design check the drawings and specifications, by referring to the "sustainability checklist" [2]. After the construction is finished, the newly built home can be also evaluated against the "sustainability checklist" [2].

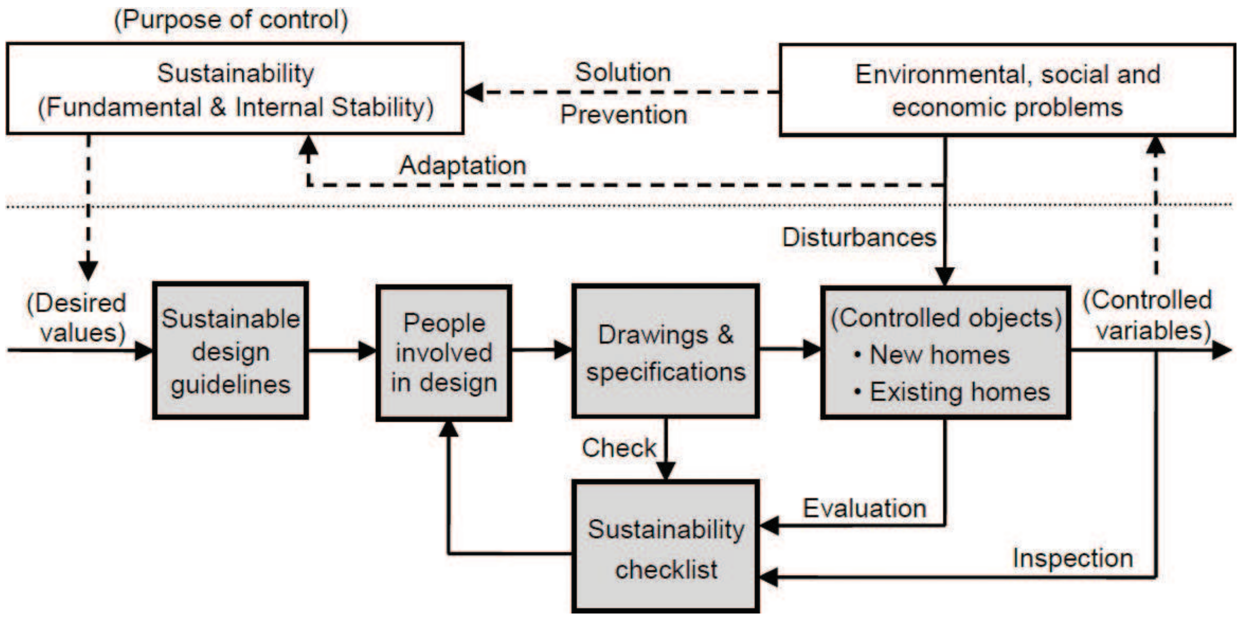

Figure 5. Control system for promoting sustainable home design [2].

3.2. Existing homes

When existing homes are the objects, the design process begins with "inspection" on the home as an object [2]. The "people involved in design" measure or estimate each element's variables of that home by referring to the "sustainability checklist" [2]. Next, they compare the measured or estimated variables with their desired values and assess the comparison results [2].

Table 4 in the previous section is equivalent to an instance of such inspection results. In addition, when inspecting an existing home and measuring or estimating variables by referring to CASBEE for Detached Houses or the JHPIS, "people involved in design" use the "Existing Building" version or "for existing homes" version, instead of the "New Construction" version or "for new homes" version, respectively [2]. "CASBEE for Detached Houses (Existing Building)" and the "JHPIS for existing homes" are almost the same as its new home version. However, the existing home version includes suitable assessment criteria for existing homes [2]. For example, as for "durability" of "exterior (outer wall, roof, etc.)," the existing home version of CASBEE shows the criteria for assessing the exterior's present condition and estimated remaining life at the assessment point of time [31].

After the inspection, the "people involved in design" usually make "drawings and specifications" for improvement, so that controlled variables satisfy their desired values as much as possible [2]. When "people involved" consider that improvement is technically difficult or costly, they can choose reconstruction instead of improvement [2]. Similar to the cases of new homes, they check the drawings and specifications for improvement or reconstruction against the "sustainability checklist [2]." Furthermore, sustainability of the actually improved or reconstructed homes can be evaluated against the checklist [2].

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