

Making a Healthy Living Space Through the Concept of Healthy Building of Building Medicine

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1. Introduction

Planning, diagnosis, and management of the healthy living space are crucial to human health management. Modern people spend at least half of the time indoor for their domestic lives, working lives, education, medical treatments or entertainment activities. Some of them even spend more than two-third of the time indoor, such as educators or health professionals. In terms of medical science, four categories affect the health of modern people—genetic inheritance, environment, life style, and health care. The environment category includes biological, physical and chemical factors, such as bacterium and excess funguses which influence indoor air quality (IAQ), radiation in buildings, and formaldehyde in harmful building materials. Furthermore, World Health Organization (WHO) also set forth a set of standards for healthy buildings, which lists fifteen recommendations for building planning. These standards are closely connected with the planning of healthy indoor environment.

This study aims to diagnose and manage healthy living space with the concept of healthy building in the field of Building Medicine. This subject can be divided into three parts: Physical Health of the Buildings, Environmental Health, and User's Safety and Health. More emphasis is placed on the aspect of the Users' Health. It is hoped that through the investigation of the interrelationship between problems in building environment with human health, harmful elements which damage the health of building occupants can be discovered. Also, with the assistance of non-destructive testing technology, cases are diagnosed following WHO's standards on healthy buildings and health hazards hidden in the environment are pointed out to readers. These hazards include: harmful building materials, radiation emitted by steel bars, high frequency electromagnetic waves, electromagnetic fields (EMF), residual chlorine in drinking water, turbidity of drinking water, pH values in drinking water, noise, sunlight ratio, temperature and humidity, O₂ content, hazardous particles, total volatile organic compounds (TVOCs), formaldehyde, CO, CO₂, and O₃. Finally, following the concept of human medical science, this study suggests remedies and preventive measures for these problems so that the problems can be diagnosed and treated early, which is parallel to the secondary prevention stage of the disease prevention in medical science.

2. Building Medicine

Building Medicine is a new management perspective, which is mainly applied to the management of buildings' health (including home living environments.) In the field of engineering, the discussion on building health management used to be only limited to proposals of ideas that the engineering field should learn from health management practices of human medicine. In contrast with these general ideas, the discipline of Building Medicine not only fully defines how to apply the model of human health management analogously, but also develops application tools based on its theories, such as Building Diseases Classification (BDC), Building Medical Record (BMR), Building Doctor Navigation System (BDNS), Building Physiology Information System (BPIS) and Building Health Diagnosis (BHD).

2.1 The theory of Building Medicine

The management concept of Building Medicine is that the behaviours and management models of human health and building health are similar in terms of their structures, functions, life cycles, and service years. Theories, methodologies, mechanisms or roles played medical science can be applied analogously to building health management. The analogous application considers theories and practices of the building construction and maintenance, evaluates constraints and limitations in applying human medicine approaches to building health management. The goal of building health management is to uphold the health and safety of the buildings and their occupants or even to promote the sustainability, environment friendliness, artistry or economical benefits of the buildings. Furthermore, the study will further explore how the theories of medical science can be applied analogously to buildings at different stages of their life cycles, such as its health system, legal framework, health promotion activities, emergency treatments, diagnosis procedures, patient care, health administration, pathology or misdiagnosis (Chang, 2006).

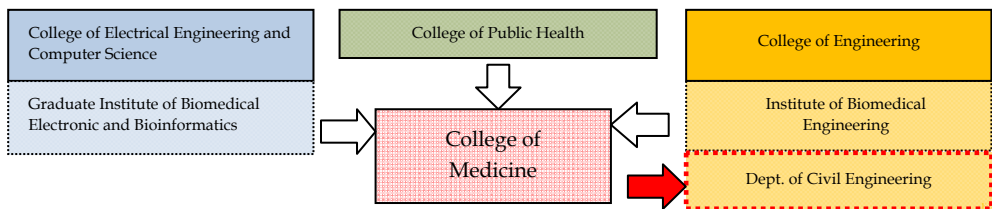


Fig. 1. Reverse thinking: Enhancing the research strength of technological and engineering fields by borrowing concepts from medical filed

As shown by Figure 1, except for the public health field, which has a close tie with the medical field, the currently available educational and technological applications are more oriented toward the field of electrical engineering, computer science, or civil engineering. Applying these technologies to medical treatment or research is part of the trend of cross-disciplinary collaboration, which can be also seen in the organization restructuring of academic institutions. For example, in National Taiwan University, the Institute of Biomedical Engineering was founded under the College of Engineering in 1988, and Graduate Institute of Biomedical Electronic and Bioinformatics was created under College of Electrical Engineering and Computer Science in 2006. The two institutes were established to enhance the research strength of the medical science field. In contrast with the support lent to the medical field by the engineering field, the concept of Building Medicine takes a

reverse turn of thinking: In view of the speedy progress and thorough thinking of medical field, why not apply its well-developed health management mechanism and methods in the medical field analogously to building health management? In this way, architects or civil engineers who not only know how to design and construct buildings, they can also learn how to be building doctors and safeguard building safety and healthy living environments.

2.2 Roles played by Building Medicine

In medical science, cares and treatments are provided to humans from their birth and death. Based on its development trajectory, three roles are played by medical science. First, patients' pain is relieved and their health is restored through 'health care'. Second, through 'scientific researches,' causes and mechanisms of the diseases are investigated, and new treatments are discovered and developed. Third, through 'medical education,' knowledge of medical science and technology is passed down, and the bedrock of health care service and medical researches is constituted (Hsieh, 2003). The same principles are also applied to Building Medicine. Although the subject managed by Building Medicine is a building, Building Medicine also play similar roles as medical science does. It maintains a building's health through health care, scientific researches, and medical education of buildings. The safety and health of the occupants can only be safeguarded on the condition that the occupied buildings are in a healthy state. See Figure 2 for the roles played by Building Medicine. Pathology is one of the discipline under medical education. Similarly, building pathology (Watt, 2007) is also developed in the filed of civil engineering. Wang & Yau (2002) pointed out in their book, *Building Pathology*, building health can be compared analogously with human health. Therefore, a large amount of human pathology studies have been carried out to understand the essence of diseases and find their treatment and prevention methods.



Fig. 2. Roles Played by Building Medicine

Building Medicine is not a discipline of pure theories. It has already been practiced on real cases. The author has already undertaken the three roles of Building Medicine outlined in Fig. 2. For the role of Health Care of Buildings, the previous position held by the author in the asset management industry was a consultant for household health diagnoses. Even though he is an assistant professor in Feng Chia University now, he teaches a service-learning course (Course Title: Building Diagnosis Technology) and leads students to provide test service of hazard factors in public environments of communities. For the role of Scientific Researches of Building, recent researches on application technologies are shown in Section 2.3 of this paper. The author also advised many master's theses which discuss diagnoses and solutions on health hazard factors in household environments, such as detection of EMF in living environments (Ma, 2010). As to Medical Education of Buildings, he opens many courses to teach students how to plan, make diagnoses, manage, and maintain a healthy living

environment, including Building Medicine (post-graduate programs), Building Health Diagnosis (undergraduate program), Building Diagnosis Technology (undergraduate program), and Intelligent Living Space (undergraduate program).

2.3 Implements for Building Medicine

Until now, several analogous studies based on the concepts of Building Medicine have been conducted. For example, a Building Medical Record (BMR) is designed analogously to medical records used in medical science; a Building Diseases Classification (BDC) is designed analogously to WHO ICD-9-CM (The International Classification of Diseases, Ninth Revision, Clinical Modification) Codes; a Building Doctor Navigation System (BDNS) is designed analogously to electronic diagnosis systems used in hospitals; a Building Physiology Information System (BPIS) is designed analogously to measuring blood pressure, pulses and temperature of human bodies; and a Building Health Diagnosis (BHD) is designed analogously to regular health checks taken by people.

1. BMR: The problem-oriented medical record (POMR) which has been generally adopted in medical science was derived from the problem-oriented recording (POR) proposed by Dr. Laurence Weed in 1964. After 1968, the POMR was gradually formed (Chen, 2001). The problem-oriented medical record (POMR) is widely used in medical science. Cheng et al. (2007) adopts the concept of POMR analogously and develops Building Medical Record (BMR) in order to make diagnostic process for building health become more systematic and complete, similar to that for human health.
2. BDC: When doctors around the world make diagnoses and give treatments to patients, the classification coding of human diseases, ICD-9-CM, is an important common language for communication between them. ICD-9-CM also serves as a reference guide for governments to determine reimbursement rates for medical services, and it is also a universal basis for statistical analyses within medical database systems. Therefore, ICD-9-CM is crucial to research and practices in the medical field. Similarly, diagnoses and statistical analyses of building diseases require a common communication language. Chang (2008) follows the logic of ICD-9-CM and applies it to the development of Building Diseases Classification (BDC) suitable for diagnosing building diseases. BDC includes Disease Code, Treatment Code and Supplement Code.
3. BDNS: The design logic of medical records aims to make records more organized, cohesive, credible, and easier to track and verify. In operation/maintenance stage of building life cycle, maintenance records are important reference data for on-site building managers when diagnosing the condition of facilities and making treatment decisions. However, three common problems often arise in the use of maintenance records. First, the inputs and updates of maintenance records and knowledge from internal sources may be unorganized and they may not be verified by practices on actual cases. Second, data and knowledge obtained from external sources may lack credibility. Third, the large quantity of data may not be able to be processed. As a result, Building Doctor Navigation System (BDNS) has been developed based on the author's BMR research. Through knowledge extraction method that combined the semantic indexing and the clustering analysis technology, BDNS can make up for the shortcomings of the systems built by private property management companies and help on-site building managers to solve the aforementioned problems encountered when building database of maintenance records. Managers or users can look up information

in cloud database via mobile devices. By doing so, they can obtain real-time and correct information regarding to diagnoses on building diseases, treatment measures, and prevention strategies, etc. See the left picture of Fig. 3.

4. BPIS: Physiology signs of human bodies are a basis for human health checks. From the viewpoints of Building Medicine, physiology signs of buildings (temperature, humidity, stress, strain) hold the same importance to building health management. Since a significant amount of human power and time can be saved by using computer systems to maintain buildings' functions and performances and extend their service years, Chang (2010) built a computer system: BPIS. After smart humidity/temperature information materials being installed inside buildings, signals detected by the materials are sent to BPIS wirelessly. Then, building managers are able to consult the detection data through the user interface of BPIS, and quickly learn about the temperature and humidity values inside the building structures (just like temperature and blood pressure measurement of human bodies.) Therefore, BPIS makes buildings become smart buildings with self-detection ability. Furthermore, BPIS also provides auto-alert function which can help managers discover problems right when they arise (see the right picture on Fig. 3).



Fig. 3. User control panels of BDNS (left) and BPIS (right)

5. BHD: Building Health Diagnosis is one link of preventive maintenance management of Professional Maintenance Management (PMM). BHD is conducted by personnel with building diagnosis training background. Based on their knowledge and techniques, they make diagnoses periodically or sporadically on various aspects of building maintenance and management, such as safety, health, performance, environmental impacts, appearance, energy conservation, and sustainability, etc. When it is necessary, maintenance and renovation works are carried out to safeguard users' safety and health, maintain the proper function of the buildings, protect environments, conserve energy and improve the urban aesthetics (Chang et al., 2007). Due to these considerations, the author has opened two courses related to BHD-Building Health Diagnosis and Building Diagnosis Technology—in order to teach building diagnosis knowledge and technology under the concept of BHD and train students to equip with the fundamental knowledge for becoming building doctors in the future.

2.4 Healthy Building of Building Medicine

Healthy Building of Building Medicine is a concept which combines medical science, public health, civil engineering, architecture, environmental engineering, and it stresses on

maintaining the physical health of buildings, including the health of their indoor environments, because healthy buildings are prerequisite for maintaining users' safety and health. Furthermore, from the point of view of sustainability, impact to the environment must be lessened as much as possible by current technology. See Fig. 4.



Fig. 4. Concept of Healthy Building in Building Medicine

Traditionally, the field of civil engineering focuses on buildings' physical health, for example, shock resistance of the structures. The architecture field emphasizes the aspect of architectural physics, such as acoustics, lighting, thermal environment, air quality, and humidity. For example, Chiang (2001) defines healthy buildings as 'A way of experiencing indoor environment of buildings, which includes physical measurements (such as temperature and humidity, ventilation aeration efficiency, noise, light, and air quality), and subjective psychological factors (such as layouts, environment colour, lighting, space, building materials, job satisfaction, and interpersonal relationship).' Furthermore, the field of green architecture has also discussed the subject of healthy buildings. For example, healthy buildings promoted by the Healthy Building Network (2011) also stressed the impact of hazardous building materials to environmental health. Health Care Without Harm is a medical organization concerned about issues of healthy buildings. Until 2010, 494 organizations in 53 countries have joined force to promote green hospital buildings and devote attention to the impact of hazardous materials to human health (Health Care Without Harm, 2010). Also, 15 planning standards are recommended by Healthy Household Guidelines of World Health Organization:

- Low concentration of chemicals which may trigger allergies
- In order to meet the requirement in the first point, avoid using ply-woods or wall renovation materials containing chemicals not easy to vaporize
- Install ventilation system of high ventilation function to emit indoor pollutants to outside. Central ventilation systems with air-supply ducts must be installed in spaces of air-tightness or thermal insulation design
- Local exhaust ventilation systems must be installed in kitchen or smoking areas
- The temperature of living rooms, bedrooms, kitchens, toilets, hallways, bathrooms must be kept at 17°C~27°C year-round
- Indoor humidity must be kept between 40%~70% year-round

- Concentration of CO₂ must be under 1,000 ppm
- Concentration of suspended particles must be under 0.15mg/m²
- Noise volume must be under 50 dB (A)
- The house should be lit by the sun for at least 3 hours/per day
- Install lights of sufficient illumination
- Households must be equipped with sufficient ability to withstand natural disasters
- Sufficient floor area per capita, and ensure privacy of the occupants
- The household design must be suitable for nursing elderly and handicapped
- Since building materials contain toxic volatile organic compounds, so it is not inhabitable some time after completion of construction. During this period, the newly completed house must be ventilated

In contrast with the focuses and definition of the fields of traditional civil engineering, architecture, public health or medicine, Healthy Building of Building Medicine covers a wider range of issues. Except for the discussion of health management activities for protecting building users' health and safety, Building Medicine also concerns itself about management projects which prevent receptors from contracting diseases as a result of unhealthy buildings. Receptors which may be affected by unhealthy buildings include users, buildings, and the environments of the affected zone. The purpose of physical health management of buildings is to prevent building damages and concerns of user safety caused by building deterioration. Proper management of indoor environmental health can also prevent users from contracting environment-related diseases, such as Legionnaires' disease, allergy triggered by particles, or cancers induced by strong electromagnetic wave or radiation. Finally, Building Medicine is also dedicated to eradicate harmful environmental impacts caused by improper management or inappropriate choices of building materials (such breaking the sustainability of green buildings or adopting building materials of higher carbon footprints.)

3. Interrelationship between living space and health problems

Environmental impacts to human health have long been confirmed by the medical field. An epidemiological model that supports health policy analysis and decisiveness must be broad, comprehensive, and must include all matters affecting health. Consequently, four primary factors have been identified: (1) System of Health Care Organization; (2) Life Style (self-created risks); (3) Environment; and (4) Human Biology. Taking the analysis of cancer causes as an example, the impact degrees of the four factors are 10%, 37%, 24% and 29% (Dever, 1976). The impact degree of environment factor in cancers is 24%. People are highly concerned about cancer prevention when it comes to their health management. Many cancer insurance policies are on offer in the market. However, the possible health hazards caused by the environment factor have been often overlooked in the education and training of architects and civil engineers who design and construct physical structures and interior environments. Not only recently do the issues of green buildings and non-toxic building materials gradually become more and more important in the fields of civil engineering and architecture, and these fields start to take steps to build healthy environments for the general public.

Living space is closely related with human health problems. From the viewpoint of civil engineering field, the issue can be explored initially by looking into building materials, building physics, and building management and maintenance and searching which factor

would result in users' health problems. By doing so, it can make architects and civil engineers aware the importance of building a healthy environment at the stage of design and construction. This concept can be seen as building eugenics promoted by Building Medicine. Since there are many factors which affect health, this study cannot cover all the health hazardous factors. Therefore, this study discusses hazardous factors which are covered by current teaching and research plans of non-destructive tests on buildings.

Common hazardous factors in the living space include:

1. Noise: Increased risk for long-lasting syndromal anxiety states (Generalized Anxiety Disorder and Anxiety Disorder NOS), thus supporting the hypothesis of a sustained central autonomic arousal due to chronic exposure to noise (Hardoy et al., 2005). Sound louder than 70 decibel (dB (A)) makes people uncomfortable. Their blood vessels would start to contract, and their blood pressure would rise. And their concentration would waver, become more nervous, and affect their learning performance. Spending a long time in an environment of 85 dB (A) cause hearing impairment, sometimes even severe hearing loss. Sound louder than 90 dB (A) may affect endocrine system, trigger mood swings, anxiety and headache, and cause people more prone to make mistakes. Sound louder than 130 dB (A) results in ear pain. Sound which register 140 dB (A) or more would make eardrum burst.
2. Illumination: Light suppresses melatonin (Boyce et al., 1987) and may cause serious sleeping problems. Either excessive or poor lighting would affect human bodies. Poor outdoor lighting may cause injuries or even death because people are easier to trip and fall. Excess indoor lighting may be harmful to vision. Therefore, both indoor and outdoor lighting should be at a proper level.
3. ELF-EMF: International Agency for Research on Cancer (IARC) classifies extremely low frequency (ELF) as a possible carcinogen (Kheifets et al., 2005). Allergic reaction may be shown in a small number of people when they are exposed to ELF. The symptoms include skin rash, itchy skin, skin burning sensation, nervous exhaustion and other unspecific symptoms, such as fatigue, vertigo, nausea, palpitation, and gastric disorder.
4. HF-EMF: Research shows high-frequency electromagnetic fields (HF-EMF) with a carrier frequency and modulation scheme typical of the GSM signal may affect the integrity of DNA (Franzellitti et al., 2010). Living in an environment of HF-EMF for a long time may cause eye diseases, lower resistance against disease, higher chance of cancer occurrence, affecting reproductive systems of both sexes with possible consequence of infertility, headaches, dizziness, nausea, loss of memory, sleeping difficulties, and hair loss. Long-term influences include higher chance of Alzheimer occurrence, tinnitus, loss of balance, skin diseases, irregular pulse, arrhythmia, labored breathing, joint pain, and sore muscle.
5. Radiation: If being exposed to high levels of ionizing radiation, infants and pregnant women have a higher chance of leukaemia and solid cancer (Lane et al., 2010). It may trigger gene mutation, infertility, cataract, nausea, blood cell deformation. If pregnant women are exposed to radiation, the babies they carry are prone to mental retardation, miscarriage, polydactyl, and Down syndrome.
6. PH level of water: The impact of pH level to human health is indirect. Only extreme pH level is harmful to human bodies. When pH level of water is too low, metal water pipes will be eroded, which will cause high level of lead, copper, and zinc in water. Related studies show copper would cause acute and chronic poisoning. In Germany, copper in tap water caused a series of severe disease (such as liver cirrhosis), and other

- gastroenterology diseases (Eife et al., 1999). When pH level is over 8.0, water would be less disinfected, which would cause potential health threats. PH level of water exceeding 8.5 may cause bitter taste and produce pipe scale.
7. Water turbidity: Turbidity exceeding a certain level may result in gastroenterology diseases (Mann et al., 2007). Turbidity is one of the key indicators of drinking water quality. High turbidity means there might be micro-organisms in water particles and it would be harmful to human health. If turbidity is visible to naked eyes, the level of turbidity is usually over 5 NTU.
 8. Chloride residues in water: Consumption of drinking water with high trihalomethane content may increase the risk of melanoma and possibly of hormone-dependent cancers such as neoplasm of the prostate, the breast, and the ovary. (Marco et al., 2004) Free chloride is added in water as a disinfectant. It may cause unpleasant smell, and it may be interacted with organic matters and form a hazardous by-product. Chloride residues remaining in water pipelines are not powerful enough to sterilize and may be harmful to human bodies. Chloride residues in tap water would damage hair and skin. After chloride is being absorbed by human bodies, it enters directly into blood, and is metabolized by the kidneys. However, if people absorb an amount too large or their kidney functions are low, they would show symptoms of chloride poisoning.
 9. Temperature: High temperature may cause heatstroke, heat exhaustion, and heat cramps. Heat exhaustion means human body temperature exceeds 38.0°C. Its symptoms include profuse sweating, malaise, headache, dizziness, anorexia, nausea, vomiting, vertigo, chills, muscle or general weakness, tachycardia and hypotension, visual disturbances and cutaneous flushing. Heat stroke happens when body temperature reaches 40.5°C or higher, and its symptom is neurologic impairment. Heat stroke is a medical emergency. Patients must be given cooling treatment and their temperature must be lowered to at least 38.8°C.
 10. Humidity: Highly humid environment induce the growth of fungus, which would trigger respiratory tract irritation, allergies (Bornehag et al., 2004), rheumatism, athlete's foot, and mosquito infestation.
 11. CO: Minor carbon monoxide poisoning results in higher blood pressure, rising heart rate, higher breathing frequency, rapid and shallow breathing, chest pain, dizziness, anxiety, nausea, and headaches. Severe carbon monoxide poisoning makes people slip into coma, twitching, cardiac arrest (Goldstein, 2008).
 12. CO₂: When the density of carbon dioxide reaches 15,000 ppm or more, it would affect breathing function. When it exceeds 30,000 ppm, it would stimulate respiratory center and causes breathing difficulties (Jones, 1999), headaches, drowsiness, hyporeflexia, lethargy.
 13. O₃: Absorption of O₃ of high density would reduce lung function, increase bronchial contraction, and raise the risk of asthma attack (D'Amato et al., 2005). When O₃ level exceeds the permissible exposure limit, it would cause coughing, short of breath, headache, decreasing lung function, respiratory inflammation, decrease the resistance of lungs against contagion and toxins. In the severe condition, it may result in pulmonary edema.
 14. TVOCs: Among indoor air pollutants, total volatile organic compounds (TVOCs) are one type of common and hazardous pollutants. Many kinds of volatile organic gas are strong poison, which would suppress the central nervous system, irritate eyes and respiratory tracts, and trigger allergies in eyes, skin, and lungs (Jones, 1999). TVOCs

- existing in the environment include formaldehyde, toluene, xylene, styrene, etc. Being exposed to high level of volatile organic compounds for a long time would inflict damages to the nervous system, liver, and kidneys.
15. Formaldehyde: United States Environmental Protection Agency classified formaldehyde as a carcinogen (Salthammer et al., 2010). Direct contact with formaldehyde causes skin allergies, eye irritation, allergic asthma, and other diseases of less pronounced symptoms (Wu et al., 2003). High level formaldehyde affects the nervous system, the immune system and the liver. Long-time contact with formaldehyde would result in chronic respiratory diseases, irregular menstrual period, decreasing resistance of babies, and even respiratory system cancers (such as nasopharyngeal cancer) and deformity.
 16. O₂: When there is no sufficient oxygen, people would lose concentration, forgetful, worse vision, more difficult to lose fat, and prone to ageing. In the work environment, the level of oxygen in the air must be more than 18%. Anoxia would be triggered when oxygen level is lower than 18%. The symptoms of anoxia are nausea, vomiting, headache, drowsiness, and sleeping difficulties (Nilles et al., 2009).
 17. Particles: The harmful effects of particles include respiratory diseases, cardio-vascular diseases, and allergies (D'Amato et al., 2005). People exposed to an environment of high concentration of particles for a long time usually can not detect any pronounced symptoms at first. However, when the condition is getting worse, they would start to have asthma and more phlegm. Their asthma may be so acute that they even feel hard of breathing and rapid heart beats when walking, which makes them unable to perform any work. This condition is called particles toxic syndromes.

The indoor air quality test taken by this study included all the general items except for bacteria and fungus because testing equipments are not yet acquired. For physical environment of the buildings, the levels of noise, illumination, humidity, and oxygen are tested, and the other tested items include radiation, ELF-EMF, HF-EMF, pH level of water, turbidity, and chloride residues. In total, 17 items are tested. Of course, environmental factors which affect health are more than 17 items. However, due to the restraints of time and budget, this study only discusses items which are covered by current teaching and testing practices.

4. Building health diagnosis for public health

The application of Building Medicine is a management project which prevents building occupants from becoming ill due to staying in an unhealthy building. It manages occupants, buildings, and environments of the affected areas. Illness caused by an unhealthy environment—such as Legionnaires' disease (caused by air-conditioning,) cancer (caused by excess electromagnetic wave, radiation or harmful building materials,) allergy (caused by poor indoor air quality) or Sick Building Syndrome (SBS)—can be prevented by proper management of the building health. How these health-hazardous factors can be eliminated? From the point of view of Building Medicine, building's health should be maintained by playing the three roles of Building Medicine (see 2.2 Roles Played by Building Medicine). Besides conducting scientific researches and medical education on buildings, when engineers engage in health care of buildings to protect public health and find out signs of diseases at the early stage, building health diagnosis (BHD) is a good strategy for maintaining and managing healthy buildings.

| Diagnosis Items | | Sources of Problems |
|-----------------|----------------------------|---|
| 01 | Noise | Public facilities (such as motors or transformer boxes), modes of transport, events or activities, public address systems, construction works, airports, factories, railways |
| 02 | Illumination | LED advertisement board (too bright), insufficient natural light, poor lighting, no lighting equipment installed |
| 03 | ELF-EMF | Indoor air-conditioning, computers, speakers, television sets, refrigerators, electric water boilers, and other electrical appliances Outdoor electric boxes, machinery rooms, utility poles, cables |
| 04 | HF-EMF | Radio, mobile phone base stations, wireless handsets, wireless local area network (WLAN), blue tooth, radar, radio stations, and wireless TV signals |
| 05 | Radiation | Building materials polluted by radiation, laboratories, areas adjacent to hospital radiology rooms |
| 06 | PH level of water | Water supply piping, improper processing of raw water |
| 07 | Water turbidity | Pollution of water supply piping, improper processing of raw water |
| 08 | Chloride residues in water | Water supply piping is too long, improper processing of raw water |
| 09 | Temperature | Geography and climate, bad ventilation of the environments, improper design of air-conditioning |
| 10 | Humidity | Geography and climate, bad ventilation of the environments, improper design of air-conditioning |
| 11 | CO | Incomplete combustion of household heating system, incomplete combustion of vehicles or electricity generators in underground parking lots |
| 12 | CO ₂ | High occupant density, bad air exchange efficiency |
| 13 | O ₃ | Photocopiers, all-in-one printers, air cleaners |
| 14 | TVOCs | Solvent-based coating, adhesives for bonding plates and panels together in renovation |
| 15 | Formaldehyde | New interior building materials or furniture, such as carpets, PVC tiles, plywood, new sofas, chairs, wardrobes, or system furniture |
| 16 | O ₂ | Basements, storage rooms, or closed and unventilated space |
| 17 | Particles | Damp walls and ceilings, synthetic fiber, asbestos, carpets, furniture, ill-maintained dehumidifiers, air-conditioning, bedding, pets |

Table 1. Diagnosis items of BHD and source of problems

In order to promote BHD, the author has started to offer a class called Building Diagnosis Technology (BDT) in Feng Chia University. As the University was promoting the attitude of 'learning through community service', this class was designed as a long-term learning program of community service. The University agreed to allocate funds for purchasing building and environment test devices, so students not only fulfil their community service responsibility, they also can apply the knowledge of civil engineering they learned in class to health diagnosis cases in communities. The author taught students how to make use of the management concepts of Building Medicine and the diagnosing and management knowledge they had learned in the preparatory class (BHD). Then he taught them how to use test devices. Finally, students were sent to communities arranged by this community service program to

perform environment health diagnosis and practice their testing skills. Because this was a large class, the number of students made it unfeasible for them to go into each household and perform their service. As a result, the environment health diagnosis provided by BDT class was usually carried out in public space. The diagnosis items include: radioactive house test, ELF-EMF level test (community utility facilities/utility poles/substations/power towers), HF-EMF level test (mobile phone base stations/ wireless internet), environment noise test, degree of illumination in the public space (following the CNS standard), water quality test (pH level, turbidity, pH colorimeter value), humidity in public environment, IAQ air quality standard (CO/CO₂/O₃/TVOC/formaldehyde/temperature/particles) recommended by Taiwan’s Environmental Protection Administration, and the test of oxygen content. See Table 1 for diagnosis items and possible sources of problems for each item.

For the convenience of field instruction and on-site tests, the devices used in this study are all handheld readout devices. Some of the devices can also be used with software for visual interface management. Although they are not expensive (the price of each device is between 500 USD to 5,000 USD), they are sufficient for introducing students to environmental education or initial tests of hazardous environmental factors. The devices used are introduced briefly below:

1. Noise: Programmable Sound Level Meter (Model: TES-1352H) is used for testing. Its test range is 30~130 dB (A), and can be used with software. See Fig. 5.

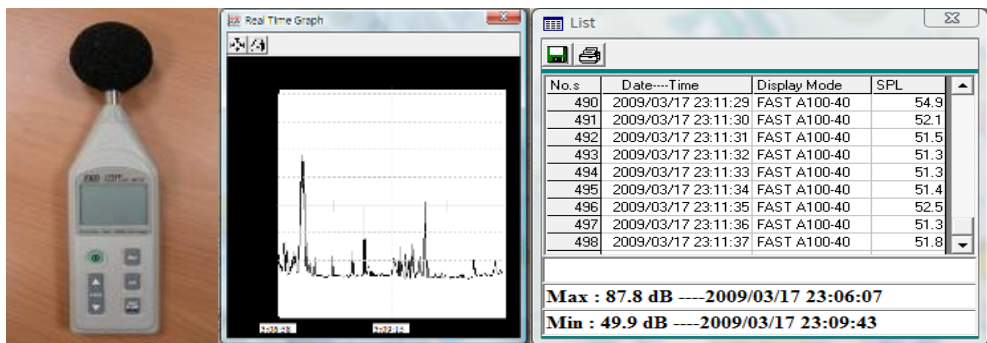


Fig. 5. Programmable Sound Level Meter and operation screen of its software

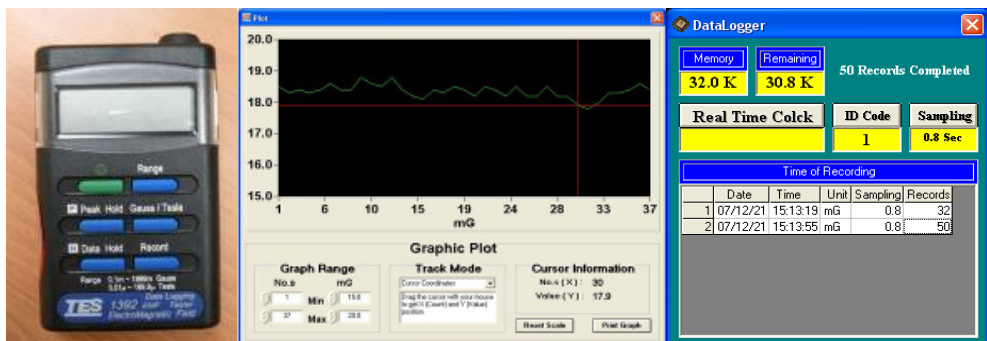


Fig. 6. EMF Tester and operation screen of its software

2. ELF-EMF: This is tested by EMF Tester (Model: TES-1392). Maximum detection limit is 2,000 mG, and its analytic precision can be as high as 0.1mG. The meter can be used with software. See Fig. 6.
3. HF-EMF: This is tested by ElectroSmog Meter (Model: TES-92). Its display resolution is 0.1mV/m, 0.1 μ A/m and 0.01 μ W/m². See the left picture of Fig.7.
4. Temperature and humidity: These are measured by Data logging Humidity / Temperature Meter (Model: TES-1365). The meter can start measuring at pre-set time. The measurement range of temperature is between -20°C~+60°C, and the measurement range of humidity is 10%~95 % RH. See the middle picture on Fig. 7.
5. Illumination: This is measured by Data Logging Light Meter (Model: TES-1336A). The measurement range is 20, 200, 2,000 and 20,000 Lux/Fc (1Fc=10.76 Lux). Sample rate= 2.5 times/per second. See the right picture on Fig. 7.



Fig. 7. ElectroSmog Meter (left)/ Humidity/Temperature Meter (middle)/ Light Meter (right)

6. Radiation: This is tested by Programmable Dosimeter (Model: PM1203M), which can detect gamma ray. The dose rate in the detection range is 0.1~2000 μ Sv/h. See Fig. 8.
7. PH level and turbidity of water and chloride residues: PH level of water is tested by digital pH Meter (Model: PH-207). The measurement range of pH level is 0~14. See left picture of Fig. 9. The water turbidity is tested by Turbid Meter (Model: TN 100). The detection range is 00.00~19.99 / 20.0~99.9 / 100~1000 NTU. See the middle picture on Fig. 9. Chloride residues are tested by Portable Colorimeter (Model: C201). The detection range of chloride residue content is 0~1.99 ppm and the detection range of total chloride content is 2.0~6.0 ppm. See the right picture of Fig. 9.



Fig. 8. Programmable Dosimeter



Fig. 9. PH Meter (left)/ Turbid meter (middle)/ Portable Colorimeter (right)

8. Content of CO, CO₂, TVOCs, HCHO, O₂, O₃ in the air: CO content is measured by CO Meter (Model: GCO-2008). See left picture of Fig. 10. The measurement range is 0~1,000 ppm and the resolution is 1ppm. The meter can be used with software. The measurement range of CO₂ Meter (Model: GCH-2018) is 0~4,000 ppm and the resolution is 1 ppm, and the meter can be used with software. See the right picture of Fig. 10.

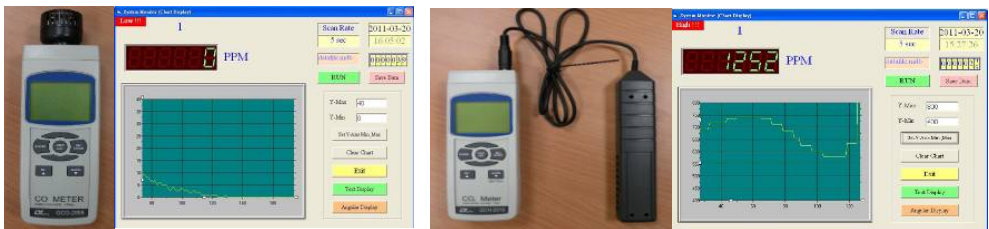


Fig. 10. CO Meter (left)/CO₂ Meter (right)

TVOCs content is measured by TVOCs Monitor (Model: Series 500). See the left picture of Fig. 11. The measurement range is 0~500 ppm, and the resolution is 1 ppm. The unit of concentration can be ppm or mg/m³. The meter can be used with software. HCHO content is detected by HCHO Detector (Model: FP-30). See the right picture of Fig. 11. The measurement range is 0~0.4 ppm, and the meter can be used with software.



Fig. 11. TVOC Monitor (left)/HCHO Detector (right)

Oxygen content is measured by GMI-Portable Gas Detector, whose measurement range is 0%~25% Vol. See the left picture of Fig. 12. Ozone content is measured by O₃ Monitor

community. It is a condominium, and its buildings are 17-years-old with 13 floors above ground and 3 floors underground. See Fig. 14.



Fig. 14. The author led students to perform radiation tests on steel bars, electromagnetic waves tests in courtyards, and formaldehyde tests in the library room

Case 2 community only has one building. The building is a 2-years-old condominium with 26 floors above ground and 4 floors underground. See Fig. 15.



Fig. 15. The author led students to perform formaldehyde tests in the rest area of SPA center, and oxygen, temperature, and humidity test in the lobby

Case 3 community is a mega-size condominium. There are 25 buildings and the number of households is more than 1,200. The number of floors above ground is from 8 to 12, and the number of floors underground is 2. See Fig. 16.



Fig. 16. The author led students to perform noise tests on sound-proof walls, illumination tests in stairways, and turbidity test on public use water

Case 4 is a case of diagnosis service performed on an elderly day care center. The center is located on the ground floor of one building. The space is divided into a rest area, a dining area, an activity area, and two bathrooms. See Fig. 17.

In the field of medical health, not all the items are tested in a health check. Health check items for each patient are recommended based on the patient's sex, age, symptoms, or living condition. Building health checks should be done this way. However, the health check cases discussed in this study are community services performed by students. Therefore, instead of

customizing the number of health check items based on the conditions of each building, all the items are performed. Students are also taught that some of the problems are less likely to happen in certain conditions. For example, the interior fitting and decoration of the Case 1 buildings have been installed for more than 10 years, which makes the problem of high formaldehyde level unlikely to happen. Nevertheless, the author still wanted students to do all the tests to verify this hypothesis, and the result can also be compared to the formaldehyde levels of new buildings' interior fitting.



Fig. 17. The author led students to perform particle test in the rest area of elderly residents and water quality tests on drinking fountains

As it is discussed above, each building's conditions vary just like every human patient's health is affected by various conditions. As a result, when making a health check plan for buildings, building doctors should consider each diagnosed subject's condition. For example, the building age of Case 1 is higher, as a result; the tests on public area should focus on water quality (the pH level), basement ventilation (CO and O₂ level), and whether indoor lighting is insufficient because of lack of maintenance. Case 2 building is younger, and it is a luxury housing project with a lot of interior decoration works. Therefore, Indoor Air Quality (IAQ) should be the focus of building health checks, such as the tests of formaldehyde and TVOCs. Case 3 buildings are located next to a night-market. The noise during the nights is louder, so the night noise test is important. As to the elderly day care center of Case 4, since the occupants are the elderly, particles which may trigger allergies or lung diseases are the focus of the test. Furthermore, the water quality test on drinking water and TVOCs test on bathroom detergents are also important.

The tests performed in these four cases have produced many valuable experience and information. However, this study follows the non-disclosure policy of medical records, and do not disclose and discuss the test result of each case (the results of most items are in the safe range). Therefore, in the following discussion, the author shares common problems and their solutions based on his 'clinical experience.'

1. Noise: The common causes of the noise level which exceeds the standard are ambulance siren, engine sounds of motorcycles, construction works, religious events held by temples, and engine sounds of ventilation fans in basements. Ambulance sirens and engine sounds of motorcycles are transient noises. Because they only last for a very short time, they wouldn't affect hearing. To lower down the noise of construction works and religious events, the occupants may report to local environmental protection bureaus and have the noise sources keep their noise down to the legal standard. If the recurring noises have constituted a psychological anxiety to occupants, it is suggested that occupants should install acoustic windows, which usually can reduce noise level up to 30 dB (A). Furthermore, the noise of the ventilation fans in basements can be reduced by installing vibration reduction devices or improving the motor's

- performance. However, if occupants would not listen to the noise for a long time, they do not need to worry about the problem.
2. Temperature and humidity: High indoor temperature would only cause discomfort of occupants. Opening windows or turning on air-conditioners would alleviate the hotness and stuffiness inside a room. The high temperature and humidity problem of underground parking lots can be solved by increasing the operation times and length of ventilation fans. Humidity measurements taken on raining days are usually higher. However, building managers still need to check if the indoor ventilation planning is adequate, and they should find air-conditioning professionals to do a close evaluation. If the water which evaporates from swimming pools spread to the entire indoor public space or households, the higher humidity tends to make mildew grow on the surface of interior fitting and decoration. When the fungus of mildew spread in the air, occupants may be prone to develop respiratory diseases or allergies.
 3. High CO content: The students once detected a value of CO content slightly higher than the standard recommended by the Taiwan government (9 ppm) in a basement. The recommendation given to the occupants was not to stay in the basement for a long time. If people need to work in the basement such as cleaning, they should turn on ventilation fans to emit carbon monoxide. However, if the air quality is still not improved after frequency of ventilation has been increased after another test by a CO content meter; the manager must check if it is due to bad planning of ventilation systems or malfunction of ventilation fans. If that is the case, they must change the planning or replace the ventilation fans. Furthermore, the news reports of CO poisoning incidents shows that CO poisoning usually happens at home in the winter, which can be explained by people tend to close windows in the winter, which results in bad ventilation, and they also do not install forced exhaust ventilation device on their gas stoves or water heaters. As a result, even if CO content measurements are normal, if the indoor ventilation is bad, it is still necessary to advise occupants to improve the ventilation.
 4. High CO₂ problem: If a crowd stay in an indoor space for a long time, the content of CO₂ tends to rise higher than the normal value. If space size is the limiting factor, the number of occupants or staying time should be lowered. If the number of occupants and staying time are both the limiting factors, it is advised to improve the efficiency and power of the ventilation systems.
 5. Illumination: Due to the consideration of energy saving or the close distance from the neighbouring buildings, the degree of illumination in some lobbies' seating areas tends to be low (for example, one is as low as 67 Lux). If the area is simply used for resting instead of reading, low lighting would not cause any inconvenience. In the daytime tests, some of the insufficient lighting areas are stairways and driveways of underground parking lots. It is suggested to install more lights. If the managers want to avoid unnecessary energy costs, they can install motion sensor lights. For the driveways of underground parking lots, the lights in some areas are often blocked by fire protection or water supply piping, so its degree of illumination does not meet CNS recommendation values. Under the circumstance, the lights can be changed to hanging lights (or adjust the location of lights slightly).
 6. Problem of TVOCs: The figures measured inside new system furniture closets tended to be higher, but the closets are usually closed so it is not a serious problem. As it is easier for TVOCs to vaporize during the summer time, building managers may use electric fans or other means of ventilation to let TVOCs flow out. High level of TVOCs was also

found in stairways, elevators, and underground parking lots, which may be caused by fresh paints or new interior fitting and decoration. Building managers should consider choosing green building materials for future renovation. If the circumstance allows, building managers may consider growing some plants which can absorb TVOCs, such as aglaonema, pleomele, dracaena, chrysanthemum, peace lily.

7. Problems of chloride residues in the water: Some of the drinking water was detected insufficient chloride residues (lower than 0.2 mg/L), which can result in improper disinfection, higher bacteria, and possible contraction of typhoid, dysentery, and cholera. Excess chloride residues in the swimming pool were also detected in some cases. Building managers should review the chloride adding process and amount, and hire professionals to test water quality regularly.
8. Problem of electro-magnetic field: Some of the indoor entertainment and exercise equipments have bigger motors. When people use these equipments, the EMF figures measured near the motors would be higher (180mG, for example). The measured figures are still lower than Taiwan government's legal standards (833mG), but the legal standard is transient exposure value, so it is not suitable to be used as a long-term safety standard. As a result, it is recommended the users should avoid using the equipments too long or keep their heads away from the motors.

6. Discussion and suggestion

As the influence of indoor air quality and indoor environment quality are so significant to human health, the knowledge of BHD is also crucial to architects and civil engineers. In 2010, an incident of carbon monoxide killed several people in an apartment building. Architects and civil engineers who had built the building faced criminal charge and were sentenced jail time because the improper design and construction of the building caused carbon monoxide flowed to different floor levels. Although the higher court is still deliberating on the appeal, it also showed the training and education of healthy environment planning, construction, and inspection are still insufficient or have been long ignored in the traditional architecture and civil engineering fields. Thus, in the future, cross-disciplinary knowledge, such as medicine, public health, and environmental protection, should be integrated to form a discipline of healthy environment planning and management which would be taught, studied and applied to the field practices of architecture and construction. In this way, architects and civil engineers are able to make sure future building users are protected from any health hazards. Furthermore, at the later stage of building lifecycle, property managers must be able to apply their management and maintenance expertise to eliminating any health hazard problems hidden in the environment or hardware of the buildings for 50 or more years of building use and management period.

There are many potential health hazard factors existing in household environments, including: hazardous gas, poor air quality, bad water quality, EMF, radiation, over-bright or insufficient lighting, noise, temperature, and humidity. Particular space, building materials, facilities, or inappropriate use habits can become the direct or indirect source of pollution. For example, bad ventilation plan (especially close or underground space), hazardous building materials (such as vaporized formaldehyde or high concentration of TVOCs), unsatisfying building material performance (such as bad sound proof performance of windows or doors), using electrical appliances for a long time and in close

distance (for example, long-time use of an electric blanket), decreasing facility performance (such as brightness of fluorescent lights reduced because they are covered by dust). In conclusion, when occupants show signs of discomfort during the indoor activities, building managers may need to check if the discomfort is caused by building environments. The association chart of building health check items, symptoms, and possible disease above (see Fig. 18) can be used as a reference. If it is necessary, professional test agencies or experts can also be brought in to maintain the health and safety of our own living environments.

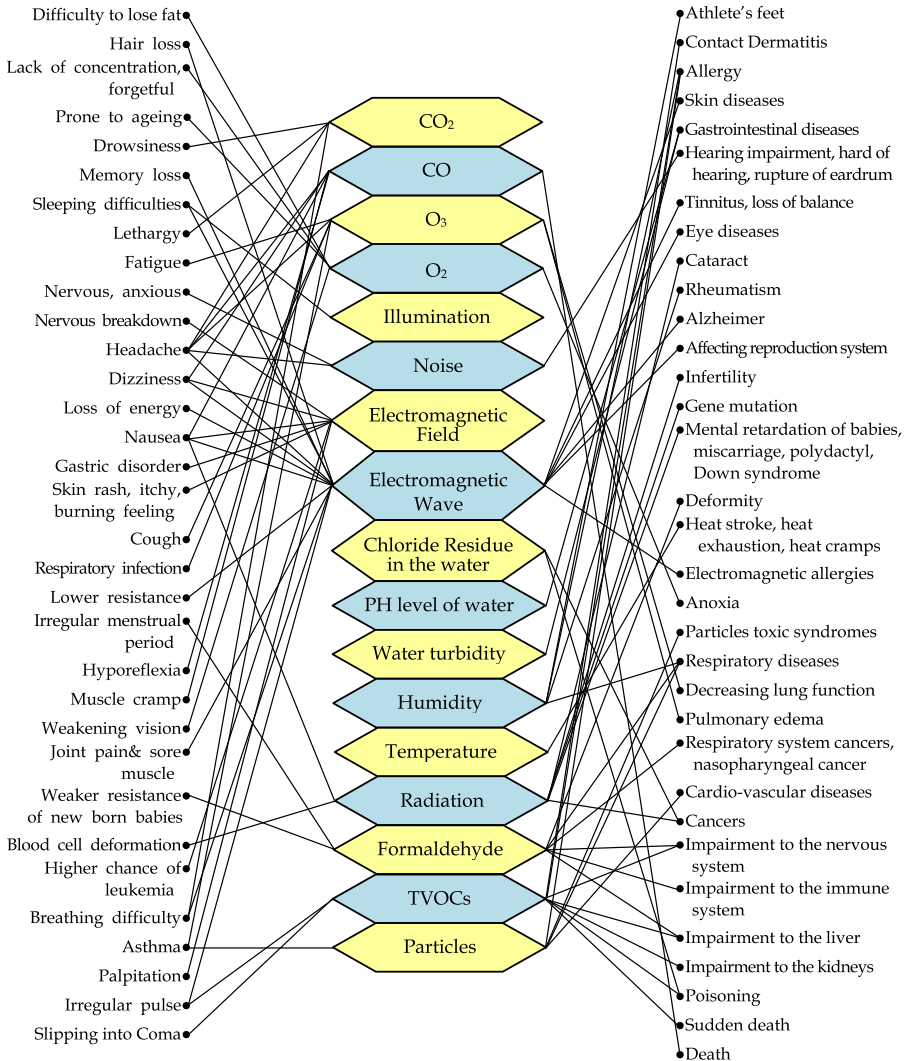


Fig. 18. The association chart of building health check items, symptoms, and possible disease

A few things must be noted when using the test devices. Before using test devices, inspectors must check if the devices are calibrated (or calibrating the devices regularly), and must make sure consumable sensor parts are within their expiry dates (such as HCHO sensing strips) to avoid inaccurate measurements. Furthermore, when performing tests with devices, inspectors also need to choose an appropriate testing location and testing time. For the choice of location, taking EMF test as an example, if inspectors perform the test in the area of electrical facilities, they will get a higher figure (see Fig. 19). However, people usually do not spend a lot of time in this area. Even if the figure is higher, as long as it is lower than the standard value, it does not need to be felt concerned, and the test report based on this result is not very meaningful. Therefore, inspectors should find the locations frequented by occupants, for example, the activity areas of elderly and children (such as the children playground in Fig. 19). Furthermore, Fig.20 shows that test of CO₂ level in the library room should be done when there are people inside so that the result would be closer to the reality. It is also more appropriate to perform the test of CO level during the peak hours because cars come in and out frequently. Tests on photocopiers should be done when the photocopiers are being operated to gather a more precise and reasonable figures.



Fig. 19. EMF tests in the electric facility area (left) and the children playground (right)



Fig. 20. CO₂ level test in the library (left) / CO level test in the basement (middle) / O₃ level test on a photocopier (right)

7. Conclusion

Undoubtedly, healthy building is a very important research subject. However, no matter how many studies on the correlation between indoor environment and health of occupants have been done to stress the importance of this subject, if there is no participation on the part of building designers, construction engineers, and managers, the importance of the issue would not be fully recognized. Therefore, architects, civil engineers and property

managers play an important role in promoting healthy buildings. Furthermore, from the viewpoint of Building Medicine, the field of construction can learn from the field of medical medicine. As a result, the model of medical field which aims to train physicians to possess the expertise of 'Holistic Care' is a feasible model for the education and training of future building doctors. By following this model, architects, civil engineers or property managers can also learn how to be a building doctor.

Based on the idea of building lifecycle, Building Medicine promotes the concept of building eugenics. If architects and civil engineers starts to evaluate how to construct a healthy building at the design and construction stage of building lifecycle, such as using green building materials or non-toxic building materials, eliminating noise problems, illumination and lighting, ventilation, EMF problems, and water supply problems, they can provide a healthy living and work environment for the public. Unfortunately, beautiful exteriors, low costs, maximum investment benefits are goals which most building developers pursue. Therefore, architects and civil engineers must develop their expertise in planning and management of healthy environment, and use their expertise to influence developers or government owners gradually. At the operation and maintenance stage of building life cycle, property managers can continuously monitor, manage, and eliminate health hazard factors in the living and working environment through regular Building Health Diagnosis (BHD) to make building occupants enjoy a healthy living space forever.

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