# Training Handbook: Sustainable Interior Installation and Building Industrialisation

# Imprint

Title: Training Handbook: Sustainable Interior Installation and Building Industrialisation

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# 1. Development History and Current Status of Construction Industrialization

Taking the road of new-type industrialization with Chinese characteristics and promoting new-type of construction industrialization development is a major strategy determined by the Party Central Committee and the State Council in the new period. It is an important measure in building moderately a prosperous society. Promoting new construction industrialization development in housing and urban-rural development areas is an urgent and important strategic mission concerning housing and urban-rural overall development; it is also an important manifestation of implementing the scientific development concept.

## 1.1 The Connotations of New Construction Industrialization

The new construction industrialization is the mode of production with the main features of applying standardized design, factory production, assembly construction, integrated decoration and information technologies management, and also forms a complete and organic industrial chain in the aspects of design, production, construction and development. The aims are to achieve industrialization, intensification and socialization in the whole process of housing construction, thereby to enhance the quality and efficiency of construction projects and to achieve energy conservation and resource saving. New construction industrialization is a profound transformation of the traditional production mode of housing and urban-rural development, a deep integration of construction industrialization and information technologies, an effective way to enhance quality and efficiency of housing and urban-rural development. It is a specific manifestation of implementing the spirit of 18th CPC National Congress.

First, new construction industrialization is driven by information technologies. The “new-type” mainly refers to information technologies, reflects in the deep integration of information technologies and construction industrialization. In the new development stage, industrialization driven by information technologies is a revolutionary leap-forward development. From the perspective of future development of construction industry, information technology will be an important tool and method in construction industrialization. It mainly reflects in the application of Building Information Modeling (BIM) technique in construction industrialization.

Second, new construction industrialization is to leave the traditional development mode of path dependency. New construction industrialization is a profound transformation of production mode. For a long time, domestic construction industry has been a labor intensive industry, mainly depending on low labor cost and the operation mode of contracting instead of managing. Compared to other industries and foreign peer industries, our construction industry has many manual work, low industrialization level, low labor productivity, frequent occurrence of construction project quality and safety problems, high energy and resource consumption during construction process, severe environmental pollution and low building life cycle. Over the past 30 years of reform and openness, other domestic industries have undergone fundamental changes and modernization level has been increasing. However, construction industry is developing slowly; the decentralized, low-level and inefficient traditional handicraft production mode is still dominating in the industry. The problems and contradictions accumulated in the traditional mode are becoming increasingly prominent. At this stage, the traditional development and production mode of urban-rural development still have a high path dependency. There still stubbornly exist conservative and dependency aspects of technology, profit, concept and scheme, etc. With the reducing of domestic demographic dividends and increasing labor cost, the traditional mode is difficult to sustain and has to transform to new industrialization mode.

Third, new construction industrialization is for construction engineering to achieve socialized mass production. New construction industrialization is to include construction engineering into the range of socialized mass production, so that it gradually transfers from traditional extensive production mode into socialized mass production mode. The prominent features of socialized mass production are specialization, collaboration and intensification. Developing new construction industrialization is in line with the requirements of socialized mass production, because the final products of construction industrialization are housing buildings and they are systematic products. Its production and construction processes must be coordinated by production enterprises of different professions. Meanwhile the construction and production of housing and its products must be specialized and standardized, with a certain degree of sophistication and scale requirements. Therefore, developing new construction industrialization can better realize the specialization, cooperation and intensification of engineering construction. New construction industrialization development is a systematic, comprehensive and directional issue, which not only helps to promote the technological progress of the whole industry but also helps to unify all aspects of research, design, development, production and construction. It clarifies objectives, coordinates actions and promotes the socialized production mode of whole industry.

Forth, new construction industrialization is positively interacting and simultaneously developing with urbanization. Currently, domestic industrialization and urbanization processes are accelerated, reaching 40% and 51% respectively. It is a critical period of modernization. During the rapid development of urbanization, it should not only focus on the economy stimulation effect of large scale construction but neglect the opportunities brought by urbanization to the transition of rural migrant workers, also cutting the connection between urbanization and construction industrialization. In the process of interactive development of construction industrialization and urbanization, on the one hand rapidly developing urbanization and the expanding construction scale provide good material foundation and market condition to construction industrialization development; on the other hand construction industrialization brings new industrial support to urbanization, industrialized production could effectively solve the employment problem for a large number of rural migrant workers, and promote the transition to industrial workers and technical workers. In this sense, only by promoting the development of new construction industrialization and realizing the positive interaction between construction industrialization and urbanization, could better support the whole urbanization process.

Fifth, new construction industrialization is realizing green construction. Green construction refers to that during the whole construction process, resources are saved to the largest extent (energy saving, land saving, water saving and material saving), the environment is protected and pollution is reduced, buildings are healthy and housing is applicable. Construction industry is the main body of realizing green building, the pillar industry of national economy. Over 50% of fixed asset investments in this society is through construction industry to generate new production capacity or use value. In China the building energy consumption accounts for 27.5% of total terminal energy consumption, it is the largest energy consumption industry in the nation. With the optimization of standardized design, new construction industrialization reduces material and resource waste caused by unreasonable design; with factory production, reduces building wastes, sewage emission and solid waste disposal caused by manual work; with assembly construction, reduces noise emission, on-site dust, transport spill, enhances construction quality and efficiency; with information technology and depending on dynamic parameters, conducts quantitative and dynamic construction management, using the least resource input to achieve high efficiency, low consumption and environmental protection. Therefore, new construction industrialization is an effective way for urban-rural development to achieve energy conservation, emission reduction and resource saving, is an assurance to realize green construction, an inevitable choice to solve the extensive development mode problem of construction industry.

Sixth, new construction industrialization is an advanced method of the whole industry. The final product the new construction industrialization is housing building. It not only involves the main structure but also includes envelope structure, decoration and facilities. It not only involves research and design but also includes all steps during the whole processes of parts and components production, construction and development management. It is the whole process of the industry using modern technology and industrialized production method to fully transform the traditional and extensive production method. New construction industrialization forms a complete industrial chain in the whole process of housing construction, including planning and design, components production, construction, development and management, etc. It gradually realizes industrialization, intensification and socialization of housing production mode, so that resources from the whole industrial chain can be optimized and maximized in benefits. New construction industrialization has a major influential effect in the industry. In the promotion process must master complete and mature applicable technology systems must have complete and organic industrial chains, both are indispensable.

## 1.2 Development History of Domestic Construction Industrialization (generation and development background)

China's construction industrialization problem was raised in the 1950s. It has experienced three stages from generation to present, and due to the differences in political, economic and social background, the driving force and key tasks are different in each stage of construction industrialization.

### 1.2.1 Stage One

In 1956, the State Council issued *Decision on Enhancing and Developing Construction Industry,* proposed "implement factory and mechanized construction, gradually complete the technological transformation of construction industry, and gradually complete the transition to construction industrialization". It required to actively apply factory prefabricated structure and components in industrial plants, housing and some infrastructural projects, required that construction installation teams specialize and improve the degree of mechanized construction. During this period the driving force of construction industrialization was the large-scale construction demand in the early days of new China. The main goal was to improve working efficiency and the main focus was industrial buildings. In 1953, China began to develop block building (non-traditional clay brick, generally larger than clay brick size). In 1958 began the trial of fabricated wall-panel buildings, in the early 1960s there has been plots of residence districts with brick wall-panel. However, with the beginning of ten years of chaos the construction industrialization development entered a stagnant stage.

### 1.2.2 Stage Two

Since the implementation of reform and opening-up policy, the construction industrialization had a second progress. In 1978 the former National Construction Committee held Xianghe Construction Industrialization forum and Xinxiang Construction Industrialization Planning Conference, which explicitly raised the concept of construction industrialization, namely "building industrial and civil building with massive industrial production method", and proposed that "construction industrialization regarding construction design standardization, component production industrialization, construction mechanization and wall material reform as the focuses". In the 1970s and 1980s, China formulated the basic standards for construction industrialization, resulted in a number of new factories. All types of new building systems developed rapidly especially large panel buildings made remarkable progress, production technology achieved mechanization and semi-automation, in areas of Beijing, Liaoning, Jiangsu and Tianjin, etc. built wall panel production line. Over 20 large and medium-sized cities in the country actively participated in component research, developing and producing new wall panel. The massive quantities of housings in Qiansan Men Street of Beijing are the representative work of construction industrialization of that period.

However, starting from the 1990s the welfare housing system was gradually abolished, commercial residential building drove the real estate industry to a rapid grow and people started to demand diversification and personalization of residential design. Meanwhile, domestic construction industrialization level was not very high and lacked of integrated platform and the capability to fulfill individual needs. In addition, the deficiency of overall building material quality and design capabilities gradually revealed as well. The large panel buildings that were promoted nationwide had water leakage problems and the seismic performance of industrial buildings was challenged as well. Therefore, the research and development of construction industrialization once again entered a stagnant and even regress stage, most component enterprises had deficit. At the same time, the commercial concrete policy vigorously implemented by the government was one of the reasons leading to the stagnation and regression of construction industrialization.

### 1.2.3 Stage Three

Currently, although the amount of construction projects still maintains a scale of tens of billions of square meters, however, as of 2013 the urban residential area per capita has already exceeded 30m$^2$. The market will be saturated in the next few years. Hence, the driving force of construction industrialization that changed: industrial development is not only driven by large-scale construction needs, but also combining economic goals, environmental impact, quality standard, individual needs and labor market changes, etc. On the 1$^{st}$ of January 2013, the General Office of the State Council issued *Green Building Action Plan, and* explicitly raised "promoting construction industrialization". Local governments, developers, construction enterprises and production enterprises all actively increased their input. Cities like Beijing and Shanghai set up ambitious goals, local governments of Shenyang, Anhui and Shenzhen, etc. also issued encouragement policies. Developing construction industrialization in the transformation stage has different problems to solve and focuses than the previous two stages (see Table 1).

Table 1: Differences in Stages of Developing Construction Industrialization

| Three Stages | Key Policies and Activities | Driving Force | Problems | Focuses | Reasons of Stagnation |
|---|---|---|---|---|---|
| Initial stage of new China | *Decision on Enhancing and Developing Construction Industry* | Large-scale construction needs | Construction speed and efficiency | Industrial buildings | Political reasons |
| Initial stage of reform and opening-up | *Construction Industrialization Development Outline* | Large-scale construction needs | Low labor productivity, many quality problems, low overall technology progress | Residential buildings | Market reasons, policy reasons |
| Transformation Stage | *Green Building Action Plan* | Multiple factors | Increased labor costs, higher public | Overall integration (should be | — |

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| | | | requirements for building quality, sustainable development becomes a consensus | scientifically planned and rationally developed) | |

## 1.3 The Current Status of Domestic Construction Industrialization

### 1.3.1Achievements of Construction Industrialization Development

At present, the construction industrialization has initially formed a structure with vertical guidance in combination with horizontal advancement, policy guidance in combination with market resource allocation, and pilot demonstration driving in combination with regional concentration development.

(1) The pilot project of construction industrialization has a significant driving effect, the promotion mechanism has initially formulated. Currently Shenyang has been approved as an industrialized demonstration city, Shenzhen, Shenyang, Jinan, etc. 10 cities have been approved as industrialized pilot cities, approved to establish 70 national housing industrialization base. In addition, there are a number of other cities and enterprises actively applying for pilot city and base enterprises.

(2) Technical standards are continuously improving and industrial technical level has been greatly improved. Housing industrialized structure system, component systems and technical support systems are initially established. The national standard *Technology Procedures for Fabricated Concrete Structure* is officially implemented. *Industrialized Building Evaluation Standards* is issued as well. They provide technical support for industrialized projects development.

(3) The endogenous power is enhanced, market mechanism gradually progresses. Many development and construction enterprises join the work of housing industry modernization, the endogenous power for the whole construction industry to take the industrialization path has been enhancing. Local governments strive to shape market demands, providing project sources via government invested projects, especially the construction of affordable housing.

(4) Industry aggregation effect is prominent, base enterprises carry out a leading role. Industrialized construction area completed mostly by base enterprises has accounted for over 85% of national total. Aggregation level is far higher than the traditional

construction market. Base enterprises carry out the leading edge, leading many research institutions, universities, design units, development enterprises, and component production and construction enterprises to form an industrialized and collectivized development mode.

### 1.3.2 Problems in the Development of Construction Industrialization

Compared with the 75% construction industrialization level of developed countries, our construction industrialization is lagged behind in development speed, level and scale. In the case of residential housings, currently the residential area built under industrialized method (including under construction and completion area) accounts for less than 1% of total housing construction area nationwide. The initiative of enterprises to develop construction industrialization needs to be improved. The problems can be summarized in the following aspects:

(1) The overall scheme of motivating and guiding an innovative development of construction industrialization is not established. First of all, some local industry administrative departments still lack of profound understanding of promoting construction industrialization. Construction industrialization is mainly driven by market forces, but also needs active guidance from governments. Secondly, policies supporting construction industrialization are not fully in place. Currently some of the existing construction industrialization policies are not mandatory and lack of necessary incentives. Finally, policy implementation lacks of necessary supervision and feedback schemes.

(2) Construction industrialization standard system is incomplete. The establishment of construction industrialization system is the prerequisite for enterprises to achieve mass production, socialization and commercial production. Currently, the state has not issued industrial mandatory standards except the self-set standards from industrialization pilot enterprises. There is deficiency in standards of industrialization design, production, installation and acceptance stages, resulting in an incomplete establishment of construction industrialization system and falling behind the development of the whole industry. All the time the lacking of standards is the “growing pains” of China’s residential housing industrialization. The lack of relevant technology regulations leads to a difficult situation where many industrialized projects cannot be initiated, constructed or accepted. In addition the current technology development of residential housing industrialization is mainly based on single technology, lacking of effective integration and difficult to form a complete construction system.

Technology systems of residential housing industrialization should contain the basic modulus system, component systems and industrialized construction systems. Modulus system is the most basic unit of construction industrialization and the most fundamental technology system. Only by realizing modulus coordination, components production could be standardized and generalized. However, domestic modulus coordination is mainly concentrated on the structural components of housing buildings and lacks an effective modulus coordination in other residential products and component/device development. This leads to consequences such as incoordination between structural components and building design, extensive construction, severely impacted final product quality and construction efficiency, inability to develop products in serialization, etc.

(3) Failing to formulate a localized residential housing industrialization system. Although there are extensive theoretical and practical explorations on the residential housing construction system during the development of domestic residential housing, a complete generic system of residential housing industrialization has not been formulated. From construction experience, residential housing industrialization system is using specialized production mode to assemble and integrate building components into building system with superior performance products. Generic building systems must enable the prefabricated components, supporting products and connection technology to be standardized and generalized, so that components and joint structures of all types of buildings are interchangeable. Europe and Japan all have their generic building system, for example the 25 types of industrialized building systems in France and the SI technology system in Japan are all industrialization building systems mandated by the state. China needs to truly achieve the prompt development of residential housing industrialization, hence establishing an industrialization building system that suits the national situation is the problem that needs to be solved at present.

(4) Construction industrialization faces a high cost. There are too few residential housing construction projects to achieve economies of scale. From the point of view of construction costs, industrialized residential housing is more costly than cast-in-situ residential housing. The main reason is that industrialized residential housing construction is still in the stage of promotion and experiment, the overall scale is small, prefabricated components have a high molding cost which leads to costly prefabricated components, workers are not familiar with technology and leads to low construction efficiency. Meanwhile, the costs of technical workers and machinery required by residential housing industrialization are high, which increases costs. In addition, the current tax system increases burdens on enterprises. At present, most

construction industrialization enterprises need to pay taxes during production process and on-site assembly construction, so there is clearly a double taxation situation. It is estimated that double taxation would increase costs for enterprises by 10% and therefore restricting the development of construction industrialization.

# 2 Policy Supports on Construction Industrialization

In recent years, in the context of construction industrialization development, the state and local governments actively introduced relevant policies, guides and promoted construction industrialization development from different aspects.

## 2.1 National-level Policies Summary

Since 1994, there has been nearly 30 regulations, opinions, measures, outlines and rules concerning residential housing industrialization, as shown in Table 2.

Table 2: National-level Policies on Construction Industrialization

| Category | Time | Published by | Name/Measures |
|---|---|---|---|
| Guiding policies | 1994 | Ministry of Construction | *Acceptance Measures for Residential Housing Construction Initial Decoration Completion* approves that newly built housings can have "initial decoration" |
| | 1999 | State Council | Issued *Several Opinions on Promoting Housing Industry Modernization and Enhancing Housing Quality* |
| | 2005 | Ministry of Construction | Issued *Guiding Opinions on Developing Energy-saving and Land-saving Housings and Public Buildings* |
| | 2005 | Ministry of Construction, etc. 6 departments | Established and distributed*Several Opinions on Accelerating Construction Industry Reform and Development* |
| | 2013-1 | State Council | In *Notice of Forwarding Development and Reform Commission Ministry of Housing and Urban-Rural Development on Green Building Action Plan (State issued (2013) no.1),* key tasks the 8$^{th}$ project clearly raised promoting construction industrialization, actively promote residential housing full decoration. |
| | 2013-11 | CPPCC Biweekly Consultation | CPPCC chairman Zhengsheng Yu hosted the conference, suggested "construction industrialized". |

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| | | Forum | |
| | 2013-12 | National Housing and Urban-Rural Development Working Conference | Conference reports, the 7th task of 10 key tasks in 2014 explicitly points out: accelerate on advancing construction energy saving, promote the modernization of construction industry. |
| | 2014-4 | State Council | Issued *Planning on National New Urbanization Development,* explicitly raised: "vigorously develop green building material, strongly advance construction industrialization" |
| | 2014-5 | State Council | Distributed *2014-2015 Energy-saving Emission-reducing Development Action Plan,* raised "focusing on residential housings, centering on construction industrialization, enhancing the degree of support to building components production, promoting construction industry modernization". |
| | 2014-5 | National Housing Industrialization Modernization Communication Meeting | Vice-minister of MoHURD Ji Qi pointed out in the meeting: residential housing industrialization has formulated a good foundation, should further accelerates on advancing modernization development. |
| | 2014-12 | National Housing and Urban-Rural Development Working Conference | Minister of MoHURD Zhenggao Chen explicitly pointed out in the meeting: the MoHURD strives to achieve new breakthroughs in 6 aspects, the first one includes "achieve construction industry modernization new leap". |
| | 2015-1 | Ministry of Housing and Urban-Rural Development (MoHURD) | Issued *Notice on Construction Industry Modernized National Building Standard Design Special Compilation Work (first group)* |
| Technical policies | 1997 | Ministry of Construction | Approved *1996-2010 Building Technology Policy* |
| | 2005 | Ministry of | Issued N*otice on Newly-built Residential Housing Strictly Implement Energy-saving* |

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| | | Construction | *Design Standards* |
| | 2015-2 | Ministry of Housing and Urban-Rural Development | Notice on approving 9 national standard building design including *Prefabricated Concrete Shear Wall Cladding Panel* |
| | 2015-5 | Ministry of Housing and Urban-Rural Development | Distributed *Notice on Construction Industry Modernized National Building Standard Design System* |
| Policy system on national comfortable housing demonstration projects | 1999 | Ministry of Construction Housing Industrialization Center | Initiated national comfortable housing demonstration projects |
| | 2000 | Ministry of Housing and Urban-Rural Development | Issued *Management Measures on National Comfortable Housing Demonstration Projects* |
| | 2002 | Ministry of Housing and Urban-Rural Development | *Management Measures on National Comfortable Housing Demonstration Projects Applied Residential Components and Products* |
| | 2004 | Ministry of Housing and Urban-Rural Development | *National Comfortable Housing Demonstration Projects Construction Technology Essentials (2004 amended)* |
| Full decoration | 2001 | Ministry of Housing and Urban-Rural Development | Compile *Construction Regulations on Residential Decoration Projects,* approved by relevant departments to become national standards |
| | 2002 | Ministry of Housing and Urban-Rural Development | Published *Implementation Guidance on Commercial Housing One-time Decoration,* which explicitly raised that developers applying for comfortable housing demonstration project level 3A housings must decorate once for all. |
| | 2008 | Ministry of Housing and Urban-Rural | *Implementation Detailed Rules on Commercial Housing One-time Decoration* |

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| | | Development | |
| Production pilot, base policies | 1996 | Ministry of Construction | Issued residential housing modernization pilot work outline, planned to implement for 20 years in 3 stages. |
| | 2002-7 | Ministry of Housing and Urban-Rural Development | Issued *Residential Housing Industrialized Base Implementation Outline* |
| | 2002 | | Established 7 national residential housing industrialized bases, including Beixin thin-walled light-steel Structure housing industrialized base, Haier group and Zhengtai group, etc. |
| | 2005-11 | Ministry of Housing and Urban-Rural Development | Issued *National Residential Housing Industrialized Base Implementation Outline* |
| | 2006 | Ministry of Housing and Urban-Rural Development | Established *National Residential Housing Industrialized Base Pilot Measures* |
| | 2015-10 | Ministry of Housing and Urban-Rural Development | *Notice on Organizing and Applying 2016 Construction Industry Modernization Demonstration Projects* |
| Residential housing performance certification | 2002 | Ministry of Housing and Urban-Rural Development | Signed an agreement with Industrial and Commercial Bank of China (ICBC), connect the performance certification work of commercial housings launched by Ministry of Construction with the housing credit business of ICBC. |
| | 2002 | Ministry of Construction Housing Industrialization Promotion Center | Signed the "Level A Residential Housing Quality Assurance Insurance Cooperation Agreement" with People's Insurance Company of China (PICC). |
| | 2005 | Ministry of Housing and | The first national standard on housing performance evaluation *Housing Performance* |

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| | | Urban-Rural Development | *Evaluation Technical Standards* is issued, implemented since 1st March, 2006. |
| Structural system | 2015-10 | Ministry of Housing and Urban-Rural Development | Convened the working forum on *Promotion and Application of Steel Structure Buildings* |
| | 2015-11 | State Council executive meeting | Pointed out: combined with shed reform and quake-proof and comfortable housing projects, carry out steel structure buildings pilot projects. Expand the use of green building material. The meeting proposed to promote the application of steel structure in the field of construction, improve the usage ratio of steel structure in public buildings and government invested construction field. |

National-level policies point out the direction for construction industrialization development from the strategic level. Currently, the national-level promotion to construction industrialization (residential housing industrialization) mainly reflects in being guided by programmatic policies, starts with multiple aspects including implementing pilot projects, industrialization bases, national demonstration comfortable housing project and promoting structural systems suitable for national conditions. Guaranteed by the establishment of organizational institutions, economic policies and technical policies, comprehensively promote the development of housing industrialization from all aspects. However, from the current implementation results, the promotion is still not ideal. The reasons are that the policy regulatory system is incomplete; “values structural system, neglects filling system”, compulsory measures are lacking, etc. Therefore, the promotion of construction industrialization is in urgent need of nationally formulated more complete and targeted policies and regulations.

## 2.2 Local-level Policies Summary

Nearly 20 provinces and cities including Beijing, Shanghai, Zhejiang and Shenyang, etc. published guidance opinions on promoting housing industry modernization, some cities also issued supporting administrative policies. They greatly promote the practical implementation of industrialization projects. All local policies are summarized in Table 3.

Table 3: Local-level Policies on Construction Industrialization

| Region | Time | Name/Measures |
|---|---|---|
| Beijing | 2010-3 | 8 departments including Beijing Housing and Urban-Rural Development Committee *Guiding Opinions on Promoting City Housing Industrialization Beijing issued (2010) No. 125* |
| | 2010-3 | Beijing Housing and Urban-Rural Development Committee *Interim Measures for Preferential Treatment on Industrialized Housing Projects with Area Rewards Beijing issued (2010) No. 141* |
| | 2010-7 | Beijing Housing and Urban-Rural Development Committee *Management Measures for Beijing Industrialized Housing Components Usage Beijing issued (2010) No. 450* |
| | 2010-11 | Beijing Housing and Urban-Rural Development Committee distributed the notice of *Management Measures for Beijing Industrialized Housing Components Usage (trial), Beijing issued (2010) No. 566* |
| | 2010-11 | Beijing Housing and Urban-Rural Development Committee*Management Measures for Beijing Industrialized Housing Components Usage, Beijing issued (2010) No. 566* |
| | 2012-8 | Beijing Housing and Urban-Rural Development Committee*Notice on Promoting Housing Industrialization in Government-supported Housing Construction Beijing issued (2010) No. 359* |
| | 2013-3 | Beijing Housing and Urban-Rural Development Committee *Notice on Implementing Housing Industrialization Incremental Cost for Government-supported Housing Beijing issued (2013) No. 138* |
| | 2014-10 | Beijing Housing and Urban-Rural Development Committee*Notice on Enhancing Quality Management for Fabricated Concrete Structure Industrialization Housing Construction Beijing issued (2014) No. 16* |
| | 2015-1 | Beijing Interim Measures for *Interim Measures for Preferential Treatment on Industrialized Housing Projects with Area Rewards* |
| Shanghai | 2009-10 | Shanghai Urban-Rural Development and Transportation Committee *Notice on Enhancing City Housing Full Decoration Management Shanghai & Development Committee jointly issued (2009) No. 1355* |
| | 2011-8- | Shanghai Urban-Rural Development and Transportation Committee *Guiding Opinions of Further Promoting the Development of Energy-saving Housings for Housing Industry Modernization During the 12$^{th}$ Five-year* |

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| | 2013-7 | Shanghai Urban-Rural Development and Transportation Committee *Several Opinions on Further Enhancing Fabricated Building Development* |
| | 2014-6 | Shanghai Government Office issued *Shanghai Green Building Development Three Year Action Plan (2014-2016)* |
| | 2015-2 | Shanghai Government Office forwarded 7 departments including municipal construction transportation committee, etc. *Notice on the Several Opinions on Further Promoting City Housing Industrialization.* |
| | 2015-2 | Shanghai construction transportation committee distributed *Notice on Implementation Outlines for Several Opinions on Further Enhancing Fabricated Building Development* |
| Shenzhen | 2014-11 | Shenzhen Housing and Construction Bureau *Guiding Opinions on Further Promoting Shenzhen Housing Industrialization (trial)* |
| | 2015-8 | Shenzhen *Housing Industrialization Projects Unit Building Prefabricated Rate and Assembly Rate Calculation Detailed Rules (trial)* |
| Shandong | 2011-7 | Jinan Government Office *Guiding Opinions of Jinan Government Office on Promoting Housing Industrialization Development* |
| | 2014-7 | *Notice of Jinan Government Office on Further Promoting Housing Industrialization* |
| | 2014-8 | Jinan Urban-Rural Development Committee *Several Policy Measures on Further Promoting Hainan Construction (Housing) Industrialization Development* |
| | 2014-9 | Qingdao Government Office forwarded Urban-Rural Development Committee *Notice on Further Promoting Construction Industrialization Development Opinions* |
| Jiangsu | 2014-10 | Jiangsu Government Office *Opinions on Further Promoting Construction Industrialization and Promoting Construction Industry Transformation and Upgrade* |
| | 2015-3 | Jiangsu Housing and Urban-Rural Development Department and Province Finance Department *Notice on Organizing and Applying2015 Provincial Energy-saving & Emission-reducing (Construction Industry Modernization) Special Guiding Fund Project* |
| | 2015-4 | Jiangsu Finance Department and Jiangsu Housing and Urban-Rural Development Department notice on distributing *Notice of Jiangsu on Provincial Energy-saving & Emission-reducing (Building* |

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| | | *Energy-saving and Construction Industry Modernization) Special Guiding Fund Management Measures* |
| Hunan | 2014-4 | *Guiding Opinions of Hunan Government Office on Promoting Housing Industrialization* |
| | 2014-12 | Notice of Hunan Government Office on distributing *Implement Detailed Rules on Promoting Housing Industrialization* |
| | 2015-8 | Changsha Housing and Urban-Rural Development Department, Changsha Finance Department *Notice on Financial Subsidies for Green Construction, Industrialized Housings and Full-decoration Commercial Housings* |
| | 2015-7 | *Hunan Housing Industrialization Production Bases Distribution Planning (3015-2020)* |
| | 2015-8 | Changsha Housing and Urban-Rural Development Committee *Notice on Establishing Expert Database for Two-type Housing Industrialization* |
| Zhejiang | 2014-12 | Zhejiang Government *Notice on Distributing the Implementation Opinions of Zhejiang on Further Promoting New Construction Industrialization and Promoting Green Building Development* |
| | 2015-1 | Zhejiang Government Office distributed *Notice on Implementation Opinions of Zhejiang on Further Promoting New Construction Industrialization and Promoting Green Building Development* |
| | 2015-1 | Hangzhou Government *Implementation Opinions on Further Promoting Construction Industry Development* |
| Anhui | 2014-5 | Hefei Government distributed *Guiding Opinions on Further Promoting Construction Industry Development* |
| | 2014-12 | Anhui Housing and Urban-Rural Development Department, Anhui Financial Department *Notice on Effectively Conducting the Work of First Construction Industry Modernization Comprehensive Pilot Cities and Demonstration Bases Construction* |
| | 2014-12 | Anhui Government Office *Guiding Opinions on Further Promoting Construction Industry Modernization* |
| | 2015-2 | Anhui Housing and Urban-Rural Development Department *Notice on Distributing Anhui Promoting Construction Industry Modernization Joint Conference Participants List* |
| | 2015-2 | Anhui Housing and Urban-Rural Development Department *Notice of Anhui Housing and Urban-Rural Development Department on* |

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| | | *Establishing Anhui Construction Industry Modernization Expert Committee* |
| | 2015-9 | Anhui Housing and Urban-Rural Development Department, Anhui Financial Department *Notice of Anhui Construction Industry Modernization Comprehensive Pilot Cities and Demonstration Bases Application Work 2016* |
| Chongqing | 2014-12 | Chongqing Government Office forwarded City Housing and Urban-Rural Development Committee *Notice on Further Promoting Construction Industry Modernization Opinions* |
| Fujian | 2015-5 | Fujian Government *Guiding Opinions on Promoting Construction Industry Modernization Pilot Projects* |
| | 2015-5 | Fujian Construction Department, Development and Reform Commission and Financial Department issued notice on *Guiding Opinions on Inviting/Bidding During Implementation of Construction Industry Modernization Pilot Periods* |
| | 2015-9 | Fujian Housing and Urban-Rural Development Department *Notice on Establishing Fujian Construction Industry Modernization Expert Committee* |
| | 2014-1 | Xiamen Government Office issued *Xiamen Green Building Action Implementation Plan* |
| | 2014-10 | Xiamen Government Office issued *Xiamen New Construction Industrialization Implementation Plan* |
| Hebei | 2015-3 | Hebei Government *Guiding Opinions on Promoting Housing Industry Modernization* |
| Liaoning | 2015-2 | Shenyang Government *Notice on Distributing Several Policy Measures for Further Promoting Modern Construction Industry Development* |
| | 2013-5 | Shenyang Construction Committee *Notice on Promoting Shenyang Modern Construction Industrialization Development (issued by Shenyang Construction Committee [2013] No. 68)* |
| Henan | 2015-7 | Henan Housing and Urban-Rural Development Department *Guiding Opinions on Promoting Construction Industry Modernization* |
| Jilin | 2013-9 | Jilin Government *Guiding Opinions of Jilin Province on Further Promoting Construction Industry Modernization (issued by Jilin Government（2013）No. 28)* |
| Sichuan | 2014-7 | *Guiding Opinions of Jilin Housing and Urban-Rural Development* |

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| | | *Department on Further Promoting Construction Industry Modernization* |

Local governments actively respond to the national appeal for promoting construction industrialization, by introducing development measures according to local conditions and scoring some achievements. By analyzing in detail local policies, the measures that local governments use to promote construction industrialization development can be categorized into two types, mandatory measures and incentive measures:

### 2.2.1 Mandatory Measures

Based on the actual situation of local conditions, most of them choose to apply mandatory measures in government invested supporting housings, and some of them also apply mandatory regulations to full decoration according to local conditions. See Table 4.

Table 4: Some Regions Use Mandatory Measures to Promote Construction Industrialization Development

| Region | Policy |
|---|---|
| Shenyang | Requirement: government invested projects such as supporting comfortable housing projects that have the application condition of fabricated construction technology, all use fabricated construction technology for construction; those commercial housing development projects that are newly started inside second ring of administrative region, must have full decoration. |
| Chongqing | Requirement: decoration design of city public rental housing and low-rent housing must strictly enforce *Design Standards*, implement finished housing handling. |
| Jiangsu, Shenzhen | Requirement: newly-build supporting housings are constructed in accordance with finished housing standards/implement one-off decoration based on economic and environmental protection principle. |

### 2.2.2 Incentive Measures

Incentive measures are mainly reflected in fiscal policy, financial policy, taxation policy and land policy, etc. Locals have different focuses.

In terms of fiscal policy, some regions issue policies that offer fiscal subsidies to industrialization housing development enterprises or projects. Representative cities are Shanghai, Shenyang, Jinan and Changchun (see Table 5)

Table 5: Some Regions Issue Incentive Measures to Promote Construction Industrialization Development

| Region | Fiscal Policy |
| --- | --- |
| Shanghai | To housing industrialization projects that meet the requirements of certain prefabricated rate and relevant technical standards, further researches established prefabricated external walls are not included in gross floor area, building energy-saving special funds supporting, incremental supporting housing costs are included in project base construction cost, etc.<br><br>Issue fiscal subsidies to full decoration housings. |
| Shenyang | The calculation of Charging base of social security charges is based on deducting the costs of factory produced prefabricated components from project construction costs.<br><br>First time pay 1% of safety measure fee, the rest is properly slowed down according to project investment schedule and project planning<br>Quality assurance fee is calculated using construction cost as base number.<br>First return wall reformation fund and bulk cement fund. |
| Jinan | Further promoting housing industrialization demonstration projects by using supportive measures of subsidized loan and fiscal subsidies, support housing industrialization enterprises on technology development, standard establishment, component production and project demonstration.<br><br>Development projects that implement industrialization pilot, within the scope of laws and regulations and being approved by relevant departments, the pilot part construction area could have preferential policy of easing on the fees of supporting measures for city construction. |
| Changchun | Housing industrialization demonstration projects established by Changchun or higher-level departments, introduce foreign advanced housing industrialization equipment and technology. After projects start or equipment/technology put into use, according to national relevant policies and regulations, grant with certain subsidies and large interest subsidy from wall material collected special fund balance.<br><br>For the established housing industrialization projects, remit administrative fees and operational fees according to shanty town reform. |
| Shaoxing | For the newly built construction industrialization enterprises or newly invested projects that meet certain requirements, grant with 5% financial support according to production equipment investment of the year, maximum funding is no more than 20 million Yuan.<br><br>Set up special incentive fund for adopting new construction industrialization |

| | |
|---|---|
| | project owner enterprises, reward with 50yuan/$m^2$ according to new construction industrialization building area, maximum funding is no more than 1 million Yuan. |

In the financial policy aspect, the Ningxia Hui Autonomous Region requires that financial department grants preferential loans to those development projects complied with housing industrialization development policies, properly increase loan commitment and loan period to consumers that purchase housings with performance certification and reaching level A standard and housing that fulfill energy-saving and environmental protection requirements.

In taxation policy aspect, Shanghai and Ningxia include housing industrialization into new high-tech industries and enjoy new high-tech industry policies and relevant taxation preferential policies; Ningxia and Shanxi grant proper income tax relief to enterprises that produce/use "4 new" technologies beneficial to resource saving, environmental protection and industrialization development. Chongqing regulates that newly built commercial housing that belong to finished housing, under the condition of remaining under the same tax trading price and applicable tax rate, building area trading price under triple of newly built commercial housing transaction building area average price in the past two years within the 9 districts of the main urban zone, tax is charged after deducting 15% of decoration fee, trading price more than (include) triple is charged after deducting 20% of decoration fee.

In land policy aspect, locals use measures such as making industrialization requirements as land dealing conditions, implementing plot ratio incentives and improving punitive measures, etc, to motivate the development of construction industrialization. See Table 6.

Table 6: Some Regions Issue Land Policies to Promote Construction Industrialization T Development

| **Land Policy Features** | **Examples** |
|---|---|
| Make industrialization a condition for land dealing (Beijing, Shanghai, Zhejiang, Ningxia, Shenzhen, Hefei, Shenyang) | Shenyang Bureau of Landing Planning sets "adopting modern construction industrialized fabricated construction technology to implement construction" as land dealing condition in the announcement, and indicates in land dealing contracts and other regulatory documents. |
| | In government invested projects land construction including supporting housings, Zhejiang Province makes sure that a certain proportion of land is used for construction industrialization demonstration projects. |
| Plot ratio incentive | Beijing regulates on commercial housing projects built with |

| | |
|---|---|
| policy (Beijing, Ningxia) | industrialization method that on the basis of the originally planned area rewarded with certain building areas, no more than 3% of the sum of industrialization-implemented unit areas. |
| | Ningxia grants plot ratio incentive policy to development construction projects that meet housing industrialization development policies or to those newly built housing full decoration area accounts for a certain proportion of project construction area. That is: accounts for more than 10% of construction area, plot ratio can be increased by 1%; accounts for 50%, increased by 2%; accounts for 100%, increased by 3%. |
| Being punished for failing to meet requirements after enjoying land policies | All levels of land resource departments of Ningxia include full decoration housing area ratio, housing performance level, etc. into land dealing conditions. Developers should timely report relevant materials for supervision during project construction process. Unable to meet regulated requirements will be fined with certain penalty and cannot participate in land bidding within 2 years. |

In administrative approval aspect, Ningxia regulates that for non-local enterprises specialized in full housing decoration, offers green channel and convenient service during procedures of registration and record filling; Shenyang and Yinchuan regulate that commercial housing development projects that use full decoration are given priority in participating in all the evaluation and selection processes in project construction field.

In addition, some regions also introduce more flexible incentive policies, such as taking into account the incremental cost of implementing fabricated housing methods, and include it into the construction cost of that base project after calculation (Shanghai, Shenyang), policy-based housing projects that use industrialized building methods are determined for selling or renting prices based on actual costy (Beijing), component production investment of fabricated construction projects can be used as the basis of applying for *Commercial Housing Pre-sale Permit,* meanwhile giving support on commercial housing pre-sale fund supervision (Shenyang), etc. These policies all have a positive promotion effect on construction industrialization progress.

# 3 Reflections of Construction Industrialization Under "Industry 4.0" Background

Construction industry is the pillar industry of national economy and it plays an important role in expanding domestic demand and stimulating economy. At present, domestic construction industry is going through the critical period of industrialized transformation. This chapter combines the "industry 4.0" development strategy and analyzes its enlightenment to domestic industry transformation, and raises reflections on national construction industrialization development.

## 3.1 "Industry 4.0" Overview

"Industry 4.0" is a concept raised by German Federal Ministry of Education and Research and Federal Ministry of Economics and Technology in the 2013 Hannover Messe. It depicts the future vision of manufacturing industry and proposes that after the three industrial revolutions of usage of steam engine, scale production and electronic information technology, the forth industrial revolution will be introduced, based on Cyber-Physic System (CPS) and signified by highly digitizing, networking and self-organizing machine production. The present of "Industry 4.0" concept receives great attention and recognition in Europe and in the global industry fields.

### 3.1.1 Background

In 2011, during Germany Hannover Messe relevant German associations proposed the initial concept of Industry 4.0. Afterwards, the German Mechanical Engineering Industry Association took the lead and united experts from enterprises, governments and research institutions and set up Industry 4.0 working group, further enhancing researches on Industry 4.0. In 2013 the Industry 4.0 standardized roadmap was published. Later on, the German government also incorporated Industry 4.0 into *High-Tech Strategy 2020* so it officially became a national strategy. It had its contingency and inevitability that Industry 4.0 received recognition from all parties in a short period of time. This came from the fact that Germany has regarded industry as the cornerstone of national economic development for a long time, came from the revolutionary impact of information communication technology on industry, also from the concerns on Germany's industrial status during the new round of technology revolution. It can be summarized based on three awareness: crisis awareness, opportunity awareness and leadership awareness (Table 7).

#### 3.1.1.1 Crisis Awareness

It is well known that Germany is a traditional technology industry power country. However, under the impact of the new round of industrial technology, the traditional competitive advantage is being challenged. Some new industries lack of growth ability and countries also challenge Germany. Germany's concerns on its own development are mainly shown in new industry innovation ability, traditional industry competitive advance and national industry strategic direction.

#### 3.1.1.2 Opportunity Awareness

Facing with the deep reflection and development determination of the United States, European Union, Japan and Korea, etc., Germany starts from its own situation and determines the right development direction in the new round of technology revolution. It fully recognizes the competitiveness of its traditional advantages and believes that it should seize market opportunities, technology opportunities and industry opportunities.

#### 3.1.1.3 Leadership Awareness

In the presence of its crisis and opportunities, Germany tries to grab the global top in industry field with its leadership awareness. Leadership awareness is mainly reflected in 5 aspects, idea leadership, technology leadership, industry leadership, standard leadership and market leadership.

Table 7: Three Awareness

| Crisis Awareness | Opportunity Awareness | Leadership Awareness |
|---|---|---|
| Concerns about new industry innovation ability | Market opportunity | Idea leadership,<br>technology leadership,<br>industry leadership,<br>standard leadership, and<br>market leadership |
| Concerns about traditional industry competitive advantages | Technology opportunity | |
| Concerns about national industry strategic direction | Industry opportunity | |

### 3.1.2 Main Contents

Germany "Industry 4.0" strategy aims at using the method of a combination between information communication technology and Cyber-Physic System (CPS) to promote the transformation of manufacturing industry to intellectualization.

#### 3.1.2.1 Interconnection

Interconnection is a means of “Industry 4.0”, aiming at closely connecting devices, production lines, factories, suppliers, products and clients. “Industry 4.0” is adapted to the development trend of everything interconnected, forming an intelligent network with prevalent sensors, embedded terminal systems, intelligent control systems and communication facilities via CPS. It enables the interconnection between products and production devices, among different production devices and between digital and physical worlds. It also enables machines, working components, systems and humans to maintain a digital information communication via network.

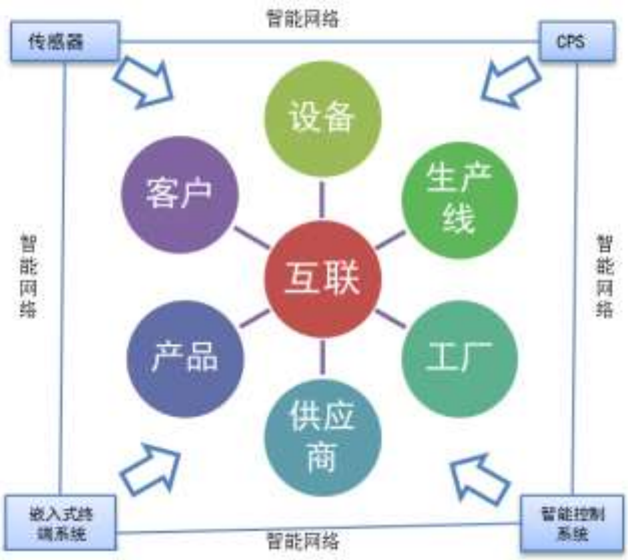



Figure 1: Interconnection

#### 3.1.2.2 Integration

Integration is the key to “Industry 4.0”. It forms an intelligent network with prevalent sensors, embedded terminal systems, intelligent control systems and communication facilities via CPS. It enables an interconnection between people, between people and machines, between machines and between services. As a result, a horizontal, vertical and end-to-end high integration is formulated.

#### 3.1.2.3 Data

Data is the guarantee of “Industry 4.0”. In the era of “Industry 4.0”, data from manufacturing enterprises will show explosive growth. With the popularization of CPS, intelligent devices and terminals, and the application of all kinds of sensors, it will lead to ubiquitous perception and connection. All production devices, sensing devices, networking terminals including producers themselves are constantly generating data. These data will be penetrated into enterprise operation, value chain and even the entire product life cycle, they are the cornerstone of Industry 4.0 and manufacturing revolution.

#### 3.1.2.4 Innovation

Innovation is the foundation of “Industry 4.0”. In the era of “Industry 4.0”, innovation is a collaborative innovation at the industrial integration level, incorporating research, industry support and standardization. This new industrialized development innovation mode breaks the restricted relationship between traditional “standardized” and “innovative” intellectual property protection. It promotes the emergence, development, standardization and transition process to economic benefits of new high-tech.

#### 3.1.2.5 Transformation

Transformation is a necessary condition for “Industry 4.0”. In the era of “Industry 4.0”, Internet of Things and Internet of Services will penetrate into all aspects of industry and will form a production mode that is highly flexible, personalized and intelligent.. Promoting the production mode will lead to large-scale customization, service-oriented manufacturing and innovation-driven.

From the perspective of the ultimate goal, “Industry 4.0” is not merely for technology. Its core is to enhance the competitiveness of enterprises, industries andeven overall the country. From the enterprises point of view, “Industry 4.0” could substantially increase labor productivity, accelerate product innovation speed and meet customization needs, reduce energy consumption, greatly enhance product quality and added-value, significantly improve core competitiveness of enterprises. From the industry point of view, “Industry 4.0” could build an innovative service system that is highly cooperative and improve the whole industry’s resource allocation and operation efficiency. From the country perspective, it is about seizing the commanding heights in the new round of industry competition.

### 3.1.3 Technology Support

Technology support has three aspects, two traction techniques for the future, two hardware and two software, three foundations based on distribution and connection.

#### 3.1.3.1 Two traction techniques for the future

Virtual reality technology is a kind of computer simulation system that creates and is able to experience a virtual world. It generates a simulation environment using computers, by using 3D dynamic vision which is a multi-source information, interactive and entity-behavior system simulation, so that users are immersed in the environment. VR is the combination of multiple technologies, including real-time 3D computer graphics technology, wide-angle stereo display technology, user head/eyes and hands tracking technology, as well as touch and force sense feedback, stereo sound, network transmission, language input and output technology, etc.

Artificial intelligence is a new technology science researching and developing to simulate, expand and extend people's intelligent theories, measures, technologies and application systems. Artificial intelligence is a branch of computer science, attempting to understand the essence of intelligence, and generate a kind of new intelligent machine that is able to react in a similar way of human intelligence. The researches in this field include robots, language recognition, image recognition, natural language processing and expert systems, etc.

#### 3.1.3.2 Two Hardware and Two Software

Two hardwares are 3D printers and industrial robots; two software are an industrial network safety and knowledge automation.

3D printers conducting manufacture by digitally adding materials.

Industrial robots are mechanical devices with multi-joint mechanical arms or high degree of freedom applied in industrial fields. They can automatically perform the job, depending on their own power and control abilities to achieve all functions. They consist of three basic parts, main body, driving system and control system, having the features of programmable, anthropomorphic and universal. Able to accept human indicators, could operate under pre-programming. Modern industrial robots could also act according to principles set by artificial intelligence.

Industrial network has far more safety risks and pressure than consumer internet. In the era of Industry 4.0, the number of identification data accessed from industry internet is huge. In addition, the complexity and management difficulties of accessing devices will be far greater than consumer internet due to the distribution and cross-industry characteristics.

Knowledge automation will play an essential role in social intelligence, intelligence industries, intelligent manufacturing, Industry 4.0 and Industry 5.0. The main methods and technologies of realizing knowledge automation are intelligent control, artificial intelligence, machine learning, man-machine interface and management based on big data. The key is from physical process automation transforming to virtual space automation.

#### 3.1.3.3Three foundations based on distribution and connection

Including Industrial Internet of Things, cloud computing and industrial big data.

Industrial Internet of Things is raised by General Motors of America, a connection and integration between global industry systems and intelligent sensing technology, advanced computing, big data analysis and internet technologies. Its core three elements are intelligent devices, advanced data analysis tools and man-machine interface. Industrial internet is a deep integration of intelligent manufacturing system and intelligent service system. It is the integration and extension of industrial system production chain and value chain.

Cloud computing is the central nervous system of the internet brain. In the structure of internet virtual brain, the central nervous system is to coordinate internet's core hardware level, core software level and internet information level so as to provide support and service to all the virtual nervous systems in the internet. Cloud computing can even allow you to experience a computing power of 10 trillion times per second. It has powerful computing ability, it could stimulate nuclear explosion, predict climate change and market trends.

Industrial big data is based on the development of emerging technologies. It expands industrial data volume using technologies such as industrial sensors, radio frequency identification, bar code, industrial automation control system, enterprise resource planning and computer aided design, etc. Industrial big data operates in high-speed in industrial enterprises production lines, is a kind of unstructured data generated by machines.

## 3.2 Inspiration to Domestic Industrial Transformation and Upgrade

Nowadays, global manufacturing industry is undergoing a profound structure change. While we accelerate on the transformation of economic development pattern, we should also seize the challenges and opportunities brought by the new round of technological and industrial revolution. “Industry 4.0” concept provides a lot of inspiration to domestic industry transformation and upgrade. In the following it will be explained from three aspects including its alignment with the domestic “information technologies and industrialization” concept, principle inspiration and measure inspiration.

### 3.2.1 Alignment with “information technologies and industrialization”

The 17th CPC National Congress aims to “strongly promote the integration of information technologies and industrialization”. It further proposes that the deep integration of “the two” is the crucial approach and inevitable choice in order to take on the new industrialization path. Deep integration of “the two” refers to that they achieve a more close connection, integration and collaboration on a broader scale, a more specified industry, a more extensive area, a deeper level, a more practical application and more intelligent aspects. Comparing with German Industry 4.0 concept, it can be seen that the industrialization phase, enterprises performance, technology basis, leading industries and operation schemes are all different for the two countries. However facing with the new industrial technology revolution and development trends, we both have the same sense of crisis and urgency and both having the strategic intention to seize the high point of the new industrial competition. Both China and Germany have similar strategies in terms of core concept, development focus and method path, etc. Specifically speaking:

(1) In terms of core concept, after revealing the cover of those new concepts including Industry 4.0, industrial internet and deep integration of “the two” (information technologies and industrialization), we can see that there are differences between concepts and strategic planning in dealing with this new industrial technology revolution for countries. However, they share the fundamental core, that the concepts of Industry 4.0 interconnection, data, integration, innovation, services and transformation are also the core concepts shared by the promotion of “the two” deep integration.

(2) In the aspect of implementation path, there are a lot of explorations in promoting quantified integration over the years and it shows the seminaries between China’s “the two” integration and Industry 4.0. Taking Zhejiang as an example, combining with its own development Zhejiang proposes the idea of six “changes” during the integration work: product replacement (realize product intelligent upgrade), replace man with machine (intelligent manufacturing devices, automation and networked), manufacturing method change (workshop devices interconnection, intelligent factories with enterprise devices interconnected ), e-commerce changes market (e-commerce expands new market), business change (cloud manufacturing, service manufacturing, etc. new business modes), management changes brain (carry the roles of cloud computing and big data in enterprises management decisions). It is essentially in line with Germany’s Industry 4.0 development path on aspects of intelligent workshop, personalized customization, data-driven and service

transformation, etc.

(3) In aspect of enterprises practice, enhancing enterprises core competitiveness is the starting and finishing point for all industrial strategic planning, for both China and Germany. From their own perspectives, Siemens, Bosch, SAP, etc. propose some demonstration plants and enterprises that could reflect Industry 4.0 features. Those conduct a series of innovations in enterprise management, business mode and production methods, ect. which are both the direction for Germany Industry 4.0 and also the direction for quantified integration of China. At the same time, domestic enterprises also carry out some positive explorations in these aspects. Home appliances, clothing and furniture industries are forming a new production method guided by large-scale customization. Innovative enterprises such as Redcollar Qingdao, Wision Furniture and Xiaomi Technology achieve a growth against trend by establishing new production model; service manufacturing business such as engineering machinery and electrical equipment are rapidly developing. Xiagu, Xugong and Zhonglian, etc. have full life cycle service, full integration and full contracting are gradually becoming the important source of enterprise profits; the collaborative supply chain management level is constantly increasing for auto, steel and petrochemical industries, Baosteel and its supplier set up an early intervention and timely production scheme.

It can be seen from the above that, from the perspectives of object, concept, path and method, the deep integration of “the two” of China is the same as Germany Industry 4.0. However, the overall industrialization level of Chinese enterprises are still lagged behind Germany, still facing with more complex and difficult tasks.

### 3.2.2 Principle inspiration

(1) The incorporation and unification of independent innovation and learning

(2) The incorporation and unification of input and output

(3) The incorporation and unification of software and hardware development

(4) The incorporation and unification of industries and enterprises

(5) The incorporation and unification of marketing decisions and government guidance

(6) The incorporation and unification of industrial civilization and ecological civilization

### 3.2.3 Measures inspiration

The new industrial concepts and methods brought by “Industry 4.0” play an essential role in industrialization transformation.

#### 3.2.3.1 Arrange and establish national cyber-physical system network platform in advance

World industrial powerful countries such as the United States and Germany all attach great importance to cyber-physical space establishment, enhance strategic foresight planning and achieve active research progress. In order to win in the future competition, China must stay a step ahead in setting up the cyber-physical system network platform. On one hand, enhancing the overall CPS planning in the new national information technologies development strategy, research and establish the CPS construction strategic goals, main tasks, development path and policy measures. At the same time, also enhancing the planning and application promotion in manufacturing industry development, intelligent city construction, national network and information safety work, etc. On the other hand, we can learn from the American “national manufacturing and innovation network center”, set up several national cyber-physical system network platforms responsible for basic theoretical research, organizing and researching on tools and equipment such as CPS software, sensors, mobile terminal devices, etc., promoting the development and application in key industrial enterprises.

#### 3.2.3.2Initiate national intelligent manufacturing major special projects

Intelligent manufacturing has become a new trend in global manufacturing industry, intelligent equipment and production means will for sure replace traditional production methods. Currently, China has initially formulated a complete industrial system in areas like intelligent measure and control, numerically-controlled machine tool, robots, new sensors and 3D printers, etc.

However, from the overall perspective the main path of domestic manufacturing industry development is still in a simple expanded reproduction way. The task of using intelligent products, technologies, equipment and concept transformation to improve traditional manufacturing industry is difficult and urgent. It is thus recommended to initiate the implementation of intelligent manufacturing special projects from the national level, enhancing on technology breakthrough, carrying out application demonstration, pushing manufacturing industry to transform into intelligent development.

#### 3.2.3.3 Guiding integration between information network technology and industry by standards.

The key of Industry 4.0 strategy is to formulate a network society where people, machines and resources are interconnected, all the data information exchange, identification, processing and maintenance between terminal devices and application software must be based on a set of standardized system. To ensure the realization of Industry 4.0, Germany ranks standardization as the first of the 8 operations, and also suggests setting up a working group under Industry 4.0 platform to deal specifically with standardization and reference architecture issues.

In the practice of promoting the deep integration of information network technology and industrial enterprises, we should also pay great attention to carry out the leading role of standardization in industry development. A timely establishment and introduction of a “deep integration of the two”: standardized roadmap and guide of the enterprises to advance information construction is needed, meanwhile, also trying to achieve globalization of the standards so that ones set by China are widely adopted by internationals, so as to seize the commanding heights and right of speech in the future industry competition.

#### 3.2.3.4 Establishing a regime ensuring systems in favor of industry transformation and upgrade.

Germany Industry 4.0 attach great importance to the issue where industrial innovation and organizational innovation conflict with current regimes. Industry 4.0 on the one hand increases the complexity of management and control, establishment of technical standards needs to comply with laws and regulations; on the other hand regulations and systems are also needed to promote technical innovation.

Industry 4.0 adopts a series of measures to enhance regime assurance, such as setting up full-time working group to deal with all issues, formulating and implementing safety support actions, establishing training and re-education systems, etc. In the matter of promoting industry transformation and update, China also faces the same issues on regime assurance. Therefore, it is highly necessary to establish and improve a long-term regime to promote industry transformation and upgrade, such as intellectual property protection system, laws and regulations in the major fields including energy-saving, environmental protection and quality safety, personnel training and incentive regimes, etc. so as to formulate a regime assurance for promoting industry transformation and upgrade.

#### 3.2.3.5 Industry-university-research jointly promote the innovation development of manufacturing industry

Industry 4.0 in Germany is jointly initiated by Acatech Germany, Fraunhofer Institute and Siemens, etc., and working group members are also composed by representatives from industry, university and research. Therefore, once the Industry 4.0 strategy is proposed it soon receives active responses from academia and industries. In fact, the motive for the government to support the collaboration of industry-university-research is not merely from market considerations. Promoting competition by collaboration and innovation of industry-university-research has become an important strategic intention of developed countries.

China should fully absorb and learn from the industry-university-research collaboration mode of developed countries. On the one hand, the government should promote the development of various types of spontaneous industry-university-research collaboration networks or industry research alliances with guidance and support; on the other hand, it should select a few key industries and key technology fields for pilot projects. Collaborations with universities and research institutions with strong scientific research ability, establishments of industry-university-research alliances in various forms, mobilization of all resources and strengths, and joint promotions of technology research and application extension should be lead by key enterprises in the industry.

## 3.3 Reflections on Domestic Construction Industrialization

At present, China's construction industry is facing a critical industrialization transformation period. There are crucial issues in aspects of design planning, technical standards, key technology and whole production chain construction, etc. In the development of construction industrialization, the problems in need of consideration are how to improve the universal technical standards, regulate on requirements, ensure collaboration of all enterprises and improve the whole production chain of construction products. In the following it will be elaborated based on construction industrialization development essential, development features and strategic points.

### 3.3.1 Development Features

#### 3.3.1.1 The change of organization

Organizations will gradually shift away from central planning and control and move to a decentralized self-organizing form. Pre-planned and inflexible production systems will gradually transfer to autonomous and self-organized production units. With wireless temporary network composed by component and processing machines, products and logistics personnel, will gradually formulate organizations and create valuable networks.

### 3.3.1.2 Intelligent products

Intelligent products already existed in the virtual world before the production of physical products. They are initially composed by several virtual components and then gradually connected with manufacturing techniques and manufacturing processes,, and then produced in intelligent factories. Intelligent products themselves can actively support production processes and at the same time Intelligent products can facilitate the clear understanding of products' operation status and possible bias occurred during working process, and also is capable of using the knowledge to control next production steps. Intelligent products can connect customer information and logistics information and at the same time to facilitate the smooth delivery of products to customers.

### 3.2.1.3 Self-control

Self-control makes the realization of product personalization easier.

### 3.2.1.4 Personnel flexibility

Working state of staff is more flexible and breaks the traditional inflexible attendance system. Experts are determining the personnel input during the production process needed within a period of time and whether there are enough workers to be allocated.

### 3.3.2 Development core

Intelligent manufacturing is the core of "Industry 4.0", which regards cyber-physical system as the core, intelligent factories as the carrier, data interconnection as the main path, intelligence of products, production, management and service lifecycle as the symbol, and customized and decentralized production method as the main feature. Intelligent manufacturing covers all stages of manufacturing industry including product design, production planning, production implementation, and after-sales service, etc.

Intelligent manufacturing is also the development core of construction industrialization. The core of Industry 4.0 mode coincides with the development goal of construction industry transformation and upgrade in China.

### 3.3.3 Strategic points

Table 8: Strategic points

| One network | （CPS）Cyber-physical System | |
|---|---|---|
| **2 themes** | Intelligent factory | Intelligent production |

<table>
<tr><td>3 integration</td><td colspan="2">horizontal integration</td><td colspan="2">vertical integration</td><td colspan="2">end-to-end integration</td></tr>
<tr><td>2 strategies</td><td colspan="3">advanced supplier strategy</td><td colspan="3">advanced market strategy</td></tr>
<tr><td>3 visions</td><td colspan="2">intelligent products</td><td colspan="2">facilities</td><td colspan="2">management</td></tr>
<tr><td rowspan="2">8 plans</td><td>standardization and reference framework</td><td colspan="2">management of complicated systems</td><td colspan="2">A comprehensive industrialized broadband infrastructure</td><td>safety and environmental protection</td></tr>
<tr><td>work organizing and planning</td><td colspan="2">training and continuous career development</td><td colspan="2">supervision framework</td><td>resource efficiency</td></tr>
</table>

#### 3.3.3.1 1 network

Cyber-Physical System (CPS) is a controllable, credible, extensible-networked physical device system that is based on environment perception and deeply integrated calculation, communication and control abilities. It realizes deep integration and real-time interaction through the feedback loop of calculation process and physical process interaction, in order to add or extend new functions. It monitors or controls a physical entity in a safe, reliable, efficient and real-time manner. The contribution of CPS is to network the physical equipment and by doing so to enable the physical equipment to have five functions: calculation, communication, precise control, remote coordination and self-control.

CPS connects virtual space and physical real world, enables intelligent objects to communicate and interact, and creates a real networked world. By using CPS technology, not only products are networked but also all the components, and thus by formulating a “super machine” which fundamentally changes the future manufacturing mode, and also develops new ways of creating value and new service models; intelligent products are identified, located and controlled in their full lifecycle, in which the most essential progress of productivity is contained. Even though products are only produced once, they can be manufactured in a profitable way. In Industry 4.0, dynamic business and project process can help suppliers to make final adjustments based on production needs and to flexibly respond to production disruptions and defects.

Industry 4.0 strategy of Germany points out that, the use of CPS could overcome the boundaries of single factory and enterprise, connect and efficiently use design resources and manufacturing resources of the whole society, and achieve intelligent production. With the development of a new generation of information technologies including big data, cloud computing and internet-of-things, internet space is rapidly evolving. One of the most important trends is that internet space itself is no longer completely virtualized but gradually integrating with real physical space as a “virtual and reality combined and inter-generated” new space. Take refrigerators as an example, under industrialization thinking the refrigerator is an independent product, apart from after-sales service its relationship with manufacturing enterprise is basically over after sold to customers. However, under internet thinking, it is the beginning of innovative services provided by all enterprises including the manufacturing enterprise. Research shows that one-third of the stored food are wasted because of deterioration in current refrigerator usage. Future refrigerators will be connected via internet, internet-of-things and CPS, which means that there is a multi-dimensional connection between manufacturing enterprises, service enterprises, food enterprises and even logistics enterprises, so as to obtain an automatic and intelligent control to prevent deterioration and acquire timely supply.


Figure 2: Cyber-Physical System

#### 3.3.3.2 2 themes

Industry 4.0 has two themes, intelligent factory and intelligent production.

The keys to intelligent factory are intelligent production system and process, as well as the realization of networked distribution of production facilities. It is the new phase of modern factory information technologies development, based on digital factory using internet-of-things technology and device monitor technology to enhance information management and service; clearly master production and sales process, improve controllability of production process, reduce manual intervention in production line, timely and accurately collect production data, proper production planning and production schedule, together with new technologies of green intelligent measures and intelligent systems to set up a base-based factory that is efficient and energy-saving, green and environmental friendly, and comfortable.

Intelligent production mainly involves the application of technologies in the production process of the whole industry, such as production logistics management, man-machine interaction, 3D printing and additive manufacturing, etc.

**3.3.3.3 3 integrations**

3 integrations are vertical integration, horizontal integration and end-to-end integration:

Vertical integration is the milestone of enterprises information technologies development, the integration of enterprise internal information flow, capital flow and logistics. It is both the integration of production processes (e.g. R&D design internal information integration) and integration of cross-processes (e.g. R&D design and manufacturing integration), and also integration of products full lifecycles (e.g. R&D, design, plan, technique, production and service whole lifecycle information integration). Industry 4.0 pursues to achieve all processes information to be connected seamlessly inside the enterprise. In the future intelligent factory, production structure will not fixed and pre-defined. On the contrary, a set of IT configuration regulations will be defined based on the actual situation of topological structure of the factory, including all the relevant requirements on models, data, communication and computing algorithms.

Horizontal integration is production chain information integration. It is a kind of resource integration among enterprises via value chain and information network. In order to achieve the seamless cooperation between enterprises It provides real-time products and service, promotes enterprises production and marketing, operation management and production control, service and finance whole process seamless connection and comprehensive integration, realizes information sharing and business cooperation between enterprises, including product development, production creation, operation management, etc.

The value chain surrounding the whole lifecycle of products creates an end-to-end integration. By integrating all enterprises resources along the value chain, it is possible to achieve a whole product lifecycle management service from product design, product manufacturing to logistics delivery and usage maintenance. Along the product value chain, it creates integration supplier (level 1, level 2, level 3…), manufactures (R&D, design, processing, delivery), distributors (level 1, level 2, level 3…), level 1 customer information flow, logistics and capital flows to provide more valuable products and services for customers. At the same time, it restructures the value system in all steps of the production chain.


Figure 3: Vertical Integration

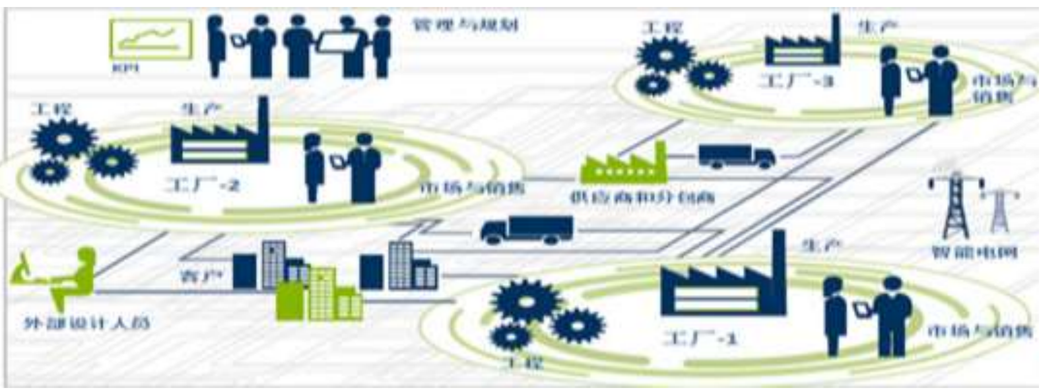



Figure 4: Horizontal Integration


Figure 5: End-to-end Integration

#### 3.3.3.4 2 strategies

Leading supplier strategy emphasizes that assembly manufacture suppliers should have technology innovation and integration, constantly providing world leading technical solutions and by doing so becoming world leading developer/producer of “Industry 4.0” products.

Leading market strategies emphasizes that manufacturing industry should be treated as the market leader and be supported. First it should promote “Industry 4.0” in manufacturing enterprises and deploy cyber-physical network system, further it should expand equipment-manufacturing industry.

#### 3.3.3.53 visions

Product, facility and management are 3 visions of “Industry 4.0”. Product integration has dynamic digital storage, sensing and communicating capabilities and carrying all necessary information required by its whole supply chain and lifecycle. Facilities are integrated by the whole production value chain, and they could realize self-organization. Management could flexibly determine production process based on current situation. (Raw) material is the same as “information”. This specifically refers to raw material purchased by factories which are “labeled”, XX product for customer A, raw material used in XX techniques. To be accurate, intelligent factories will use “raw material” containing information, (raw)material =”information”. Manufacturing industry will eventually become part of the information industry.

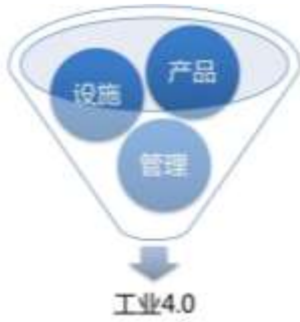



Figure 6: 3imagination

#### 3.3.3.6 8 projects

The 8 projects are standardization and reference structure, management of complicated systems, a comprehensive industrialized broadband infrastructure, safety and environmental protection, work organizing and planning, training and continuous career development, supervision framework, and resource efficiency.

# 4 Theoretical Framework - Case study of platform establishment and research on CPS industrialized construction system

With the rapid growth of China's economy and development of construction industry, there occur many problems in the construction, usage and upgrade processes of buildings, such as resource and environmental problems, industry structure problems, operation management problems, etc. Along with industrialization level increase and information technologies development, these issues require a new perspective and modern technical measures in order to be solved. Based on a long time of exploration, research and practice, China Architecture Design Group CSP R&D Promotion Center has a multi-dimensional arrangement on domestic construction industry status and expected development goals. Starting from the most basic architectural composition, it aims to integrate associated industry chain resources, incorporate domestic and foreign experiences, gradually establish a set of relatively complete theories and technologies, and to implement capable and open industrialized construction system. It strives to build a sustainable multi-layer open platform. At present, the research is still at an initial stage. It is our hope that the efforts will eventually achieve the expected goals and contribute to our strength of developing and progressing the domestic construction industry.

## 4.1 CSP Terminology Definition

CSP is short for Chinese Architecture Group (CAG) Architecture System Platform. China Group tries to set up a platform that could connect the whole construction industry and provide a possible solution for the modernization of China's construction industry,

The establishment of a system is to purposely set up a relevant logic to social resources, so that it is balanced, supplemented, developed and at the same time to more properly adjust and release resource potential, in order to generate greater compound effect. CSP regards construction products as the core of social resources related to construction products as the object; overall planning, integrated design, associated manufacturing, system maintenance and full service as the steps; energy-saving and environmental protection, safety and reliable, high quality and efficient, beneficial to the society as the goals. It is a theory, technique and implementing system established by standardized organization that runs through the whole lifecycle of buildings.

## 4.2 CSP Theoretical System

### 4.2.1 CSP theoretical basis

#### 4.2.1.1 People-oriented

The first theoretical basis of CSP is people-oriented; All buildings are serving for people - as long as it is related to human activity and it is within the scope of architecture. Buildings are essentially the container for life, therefore should fully consider people's needs, respect local culture, reflect humanistic feelings, and truly realize the basic thought of "people-oriented".

By studying ergonomics and scale space theory from the usage requirement, by taking into account the human activities in buildings and by providing a better living environment, while fulfilling the constantly growing material and cultural needs humans would also be encouraged to continuously improve their exploration ability and creativity.

#### 4.2.1.2 System theory

System theory is also known as system science, an ideology raised in the past few decades by theoretical biologist L.V. Bertalanffy. Bertalanffy once wrote "Aristotle's argument that 'the whole is larger than the sum of its parts' is a statement on basic system problems, and it is still correct". [1] The core idea of system theory is the holism concept of a system. L.V. Bertalanffy emphasizes that any system is an organic entirety, it is not a mechanical combination or simple addition of each components. The overall function of the system does not exist in any independent insolated element. He uses Aristotle's famous "the whole is larger than the sum of its parts" to explain the integrality of a system and opposes to the mechanism opinions that think good element performance leads to good overall performance and uses parts to explain the whole.

CSP mirrors the system theory in architectural science where buildings are considered as a system product and not a simple addition of parts. The reason to regard system theory as CSP theoretical basis is to adjust building system structure and coordinate between parts by using advanced technologies, so that the building system is optimal. Only by organically combining all parts of a building, could buildings be a complete, high quality and usable product.

#### 4.2.1.3Sustainable development theory

Sustainable development theory derives from the environmental pressure of economic growth, urbanization, population and resources, people's reflections on the mode of “growth=development”. In 1987 the United Nations World Commission on Environment and Development released the report *Our Common Future,* in which sustainable development is defined as: sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs [2].

CSP is based on the requirements of sustainable development, aiming at the currently existing high consumption, high pollution, low efficiency and low quality in construction industry. Its focus is not only on technique or technical system, but more importantly its active impact on society, economy and the environment.

### 4.2.2 CSP core concept

In the industry, there have been differences in understanding and subdividing constructions because of differences in objectives, perspectives and knowledge for a long time. There is no right and wrong but only differences caused by different reasons. Nowadays technology, economy and society are continuously developing, using a single perspective and traditional knowledge to understand and divide constructions are clearly outdated. When we change the way of thinking and take a look from another angle to understand constructions, we will draw some different conclusions which will help us to deepen the recognition on “construction industrialization, housing industrialization and industry modernization”. It would also help to find the ways to achieve these goals as soon as possible. The difference between these conclusions and traditional recognition is the starting point of CSP, is the structural basis of CSP theoretical system, technical system, implementing system and platform system. On the basis of these, the core concepts of CSP is analyzed, concluded, summarized and gradually formulated

The core concepts of CSP are: architecture finished product theory, architecture trichotomy and parallel equilibrium principle**4.2.2.1 Architecture finished product theory**

Housing buildings are construction products that in the concept of architectural economics are a type of final products provided to the society that are functional and used for people. They are formulated after a series of works [3] including exploration design, building construction, components manufacturing and device installation, etc. The products have standards, fundamentally different from components, fittings and semi-products. In nowadays “World of Wheels”, we can easily purchase all kinds of cars, with low specifications, high specifications or customization, but it is difficult to purchase “raw” cars. In public perception, they are not complete, usable and tradable products.

When we look at, analyzing and defining architecture from a perspective of complete, usable and tradable products, it can be easily observed that architecture is a kind of kind of usable and tradable product with certain function and necessary use condition. This conclusion defines the purpose, product features and commodity property of architecture. Obviously the rough housings existing for a long time in China are not complete architectural products. They do not have complete product performance evaluation elements and therefore can only be called semi-architecture. There are many uncertain and uncontrollable factors from semi-products to finished products, therefore it is not a surprise that there are many private dismantling caused by safety incidents that endangered the buildings.

Also there are resource wasting and improper industry structure issues in the process of semi-product to finished product. From the user's perspective, time, effort and money are required to make semi-products meeting usage requirements and are not at professional levels. From the aspect of decoration market, owners are scattered, management is not standard, process lacks connection which lead to chaotic marketing transactions and large social resources occupation, making it difficult to achieve an industrialized production model.

In order to solve the above problems CSP proposes architecture finished-product theory, that is taking finished architecture as research object, split and then sort out the connection between elements such as design, production, assembly, delivery and maintenance during construction process; use modern technology to achieve complete architectural products manufacturing and ensure its scientific, practicability, safety and diversity; emphasize on the integrity of architecture, process connection and result safety (Figure 7, 8)

Figure 7: CSP architecture. Finished product show room 1

Figure 8: CSP architecture. Finished product show room 2

#### 4.2.2.2 Architecture trichotomy

There are a wide variety of architectures in different forms, so how this diverse architecture world where we live in is constructed? The conclusion must be dazzling. The diversity of architecture shows people a variety of buildings but also make people neglect the generality within the difference, this is a world where differences and generality coexist. When we systematically split and sort out architecture from their composition and functionality, it can be clearly seen that architecture is composed of three parts: structural supporting body, outer fence body and inner filling body. All parts have their own distinctive functional elements and also interdependent connecting elements, both are indispensable.

The predecessor of architecture trichotomy is SI housing system. SI system divides housings into changeable and two immutable parts, where immutable parts include both main structure and immutable parts for residents, such as nonbearing separating walls, outer fence body and public pipes/wills, etc. The consideration of such division is allowing tenants to flexibly design and alter private living space based on their own needs, in order to increase the applicability and service life of housings. SI housing system provides an advanced and feasible solution and development direction to domestic housing industry modernization, it could prolong service life of housings, improve housing quality, promote community and urban sustainable development. Under the trend of fully promoting construction industry modernization, its basic theory can be extended to other kinds of civil buildings. After this extension it is necessary to reorganize this theoretical system.

First of all, civil buildings except residential housings cannot have space and structural classification using the concept of right of control, but only be classified by functionality and durability; at the same time, it is found during construction practice that, outer fence actually lies between changeable and immutable parts. From the point of building structure, outer fence belongs to the non-supporting body, however due to the public property of its function it has a immutable feature to some extent. In the actual situation, service life of outer fence is between structural supporting body and inner filling body. When architectural function undergoes big changes or there are other requirements, outer fence can also be changed independently or together with inner filling body. Therefore, from the aspect of functionality and changeability, outer fence body should be classified independently, and all the inside building non-structural fittings and components should belong to inner filling body. CSP architecture trichotomy theory is thus formulated, that starts from the main structural body of architecture, and divides a whole architecture into structural supporting body, outer fence body and inner filling body three parts.

Within the architecture, the structural system used for carrying, conducting and disassembling internal or external load is called structural supporting body. It is clear that prefabricated concrete structure, steel structure and wooden structure are all advanced structural forms that are adapted to construction industrialization production and assembly. The rapid growth and application of these structural forms indicates that domestic construction industrialization has made great progress. Construction structure industrialization is an importance link of construction industrialization, but not all of it.

Outer fence body is used in outer supporting body as a kind of non-structural supporting parts with functions like heat insulation, wind/rain proof, lightning and radiation protection, sun-lighting/shading, decoration, etc. Cantilevered balcony, bay window and additional fittings established due to function or design requirements are concluded as outer fence body. Architecture identification information that can be directly experienced by the public, such as style, color, material, etc. are all expressed by outer fence body. This is another important function of outer fence body in addition to the basic functional requirements such as safe protection, heat insulation, lighting and ventilating.

In the building space constructed by supporting body and outer fence body, there is also an inner filling body: wall, partition wall, ceiling, etc. used for separating the space, device, pipes, functional fittings, etc. used for usage needs, and decorations used for comfort and aesthetics. Inner filling body determines the functional property of the inside space of a building. For the same building, its functional property is a hotel when filling with hotel room facilities; its functional property is a medical facility when filling with medical ward facilities.

CSP architecture trichotomy is a classification system used for researching and disintegrating the building. Architecture as a whole product, the structural supporting body, outer fence body and inner filling body are both independent interconnected, and inseparable.

#### 4.2.2.3 Parallel equilibrium principle

On the theoretical basis of “architecture finished-product theory”, CSP formulated the parallel equilibrium principle of construction products composition system. Parallel refers to the synchronization of technology R&D and promotion/application used in construction composition system (structure, outer fence, inner filling, etc.) and project implementation system (planning, design, manufacturing, installation, and delivery/maintenance); equilibrium refers to development equilibrium, technology equilibrium, configuration equilibrium, quality equilibrium and service equilibrium. From the perspective of construction industry chain, stagnation in any link of product composition system will constrain the development of the whole industry chain. For example, while focusing on construction structure industrialization attention should also be payed to the industrialization development of outer fence and inner filling parts. Only construction structure industrialization cannot fully improve and guarantee the overall quality of construction products, and it also causes severe imbalance to the industry chain development. Another example is that while construction industrialization level is quite advanced in design, production and construction phases, then logistics and maintenance management need to research and learn about industrialization building as well, in order to formulate a corresponding management model so that the advantages of industrialization buildings can be reflected in components, such as easiness to repair and replace. Therefore, only by parallel promoting and an equilibrated development, construction industry modernization could be advanced in coordination.

## 4.3 CSP Technical System

### 4.3.1 Under united technical standards

CSP uses technical measures including parallel development, open interface, fault-tolerant and correction, data chaining, etc., to closely connect different components and stages of industry chain and eventually formulate an organic entirety.

CSP is built on the premise of a unified technical path. In the process of promoting construction industrialization, enterprises will choose the technical system and equipment fitting into their own development, based on self-awareness and all objective conditions. As a result, there are circumstances where products belong to the same category but are significantly different in technical development direction. It is understandable to have such differences in a single product category, but when it comes to establishing an overall and correlated technical implementation system, it involves different industries, enterprises and technologies, product categories are various. In order to achieve parallel promotion and a balanced development, a unified technical path must be determined. Point to area, ordered promotion and a balanced development are basic principles for determining a unified technical path. Under the guidance of this principle, should be determined the associated technical development direction and objectives, and should be compiled and formulated associated technical implementation system framework, principle, promotion stage planning, etc. In order to achieve resource integration, technology integration, function integration, market integration, and eventually achieve the goals of coordinated development and win-win situation (Figure 9).


Figure 9: CSP standard system

### 4.3.2 Parallel Development

It refers to a systematic design and development model that integrates design, all elements of construction products and their manufacturing, delivery, construction, delivery and maintenance, etc. relevant to the production process. Traditional construction projects have been adopting a serial working mode where after one stage completion start the next phase. Due to different professions and different perspectives on a problem, work in the last stage usually does not take into account the requirements of the next stage. This way of working will inevitable cause many problems, such as: device space is not enough found in construction drawings and hence going back to plan changing is required; during construction phase the material transportation cost is found to be too high and hence going back to design changing is required, causing labor, material and time loss. CSP learned the advanced product development model called parallel construction from manufacturing industry, and set up a working system for construction products parallel development (Figure 10), aiming to incorporate all relevant factors within the whole construction lifecycle in product planning phase, so as to increase working efficiency and shorten overall construction cycle


Figure 10: Construction products parallel development model

### 4.3.3 Open interface

It refers to the technology that enables components and fittings of different enterprises to be adaptively connected, including both physical interface and information interface. Interface technology enables the close connection between fractured construction production process (from planning, design, production, delivery, installation to operation maintenance) and specialized work division (construction, structure, electromechanical and decoration), so that fittings with different techniques and properties can be connected effectively, rapidly and smoothly. CSP is an open platform system, fittings, components and technologies that meet CSP unified standards can all become a part of CSP via open interface.

### 4.3.4 Fault-tolerance and correction

Construction final products are made up by a large number of components and fittings, involving many component categories and manufacturing factories, having long production cycle and greatly influenced by external conditions. There will inevitably be high tolerance during manufacturing processes. This is a key problem that construction industrialization has to solve. In order to avoid the quality and safety hidden problems caused by accumulated tolerance, in addition to set up an interconnected quality monitoring system, the CSP also needs to emphasize that associated component design must take into account a certain degree of tolerance, component design must keep a property amount of fault-tolerance space at the proper places. Meanwhile, during construction components assembly, technical management staff should properly use the tolerance of components to break down and eliminate all deviations generated during assembly process, in order to realize fault-correction. Fault-tolerance and correction is one of the important technical measures associated with industrialized construction production and assembly.

### 4.3.5 Visible construction

Unlike traditional construction methods, CSP strives to reduce or eliminate all the pre-embedded pipelines inside structural supporting body. Using measures such as scientific space planning, setting pipeline interlayer combined with decoration components, etc. during design stage, to achieve pipeline, device and functional components on-site visible construction in the construction phase by proper process planning (Figure11, 12). The objective of visible construction is not merely to ensure construction quality to be checkable and controllable, but more important to be flexible for later period visible maintenance and visible replacement. This process will not impose any impacts on structural supporting body, so thatstructural safety within construction lifecycle is ensured. CSP covers all stages of construction lifecycle, visible construction, controllable quality and changeable components, which is one of the objectives of CSP.

Figure 11: Visible construction of electric circuit

Figure 12: Completion effect

### 4.3.6 Data chaining

Data chaining refers to the information delivery and sharing along the industry chain links, it is a necessary means to achieve parallel development. Information integration will be used to achieve the data chaining between design data and component processing center, construction site and later property management data. In the ever-changing technology days, information technology development level could almost represent the modernization level of a country, an industry, an enterprise. For construction industry, only by realizing the data chaining between design, production, construction, delivery and maintenance, construction industry modernization could be truly realized.

## 4.4 CSP implementation system

CSP implementation system is composed of five parts: overall planning, integrated design, associated manufacturing, integrated construction and system maintenance. It is a whole service system involving the whole construction industry chain and whole lifecycle of buildings. All parts have independent phased tasks but also have connected elements. During earlier stage of overall planning and integrated design phase should be taken into account the later production, construction and operation, and relying on previous design and data should be prerequisite and basis. All phases interconnected with each other formulate the overall CSP implementation system

### 4.4.1 Overall planning

With the support of full service system (technical software), is carried out the necessary pre-implementation work including environment (site) planning, product planning, energy planning, environmental protection planning, cost planning, operation planning, etc. Overall planning is a means of analyzing and solving problems, it regards buildings as complete finished products that have some functions, necessary usage conditions, usable and tradable. To analyze the overall objective of construction finished products, are selected proper means to describe all parts of the entirety, between parts, between parts and overall and their relationship with the external environment, and a corresponding evaluation index system, eventually integrated into an entirety for analyzing and concluding the optimal decision for the whole situation and all objectives and decisions of component coordination.

### 4.4.2 Integrated design

With the support of full service system (technical software), the integrated design of a building should strictly follow the requirements of overall planning opinions, conduct product standard inspection; carry out product integration design including technology integration, components integration, comprehensive information (data) integration, etc.; establish 2-dimensional, 3-dimensional, data product design information chain; finish integrated device pipeline, component and construction products design, support and guide associated manufacturing, integrated construction and system maintenance. CSP integrated design is the first step of connecting with manufacturing, once a project enters integrated design phase (corresponding to construction map phase in the traditional design) it means that this construction product has finished all planning and design working in the earlier stage and started technology preparation for integrated construction.

### 4.4.3 Associated manufacturing

With the support of full service system (technical software), based on production design information chain provided by integrated design, manufacturing processes should finish the works of system disassembly, system configuration, system processing, system delivery, system installation, system fitting and system inspection. Manufacturing is an important step of construction product completion, with the development of industrialization and information technologies, manually and paper-based information delivery starts to show its deficiency. CSP uses integrated design of earlier stage products and depending on efficient delivery of information data and system disassembly to achieve high precision and high completion industrialized components production, then using digital data identification of components to achieve system delivery, installation, fitting, inspection and later maintenance.

### 4.4.4 Integrated construction

With the support of full service system (technical software), should be used construction-contracting integrated project implementation mode, on the basis of product design information chain to implement whole construction information technologies, refined management, integrating coordinated site, material, device, personnel, capital, etc. requirements and resources, and should be achieved high integration of design, manufacturing and construction. Under the mode of construction contracting, CSP construction planning is done in the integrated design phase, and formulates control data during product design information chain. Specifying components production plan, delivery information and processing schedule, is necessary in order to ensure that integrated design results are accurately and efficiently implemented.

### 4.4.5 System maintenance

As in product buildings will appear varying degrees of aging and destruction during usage process, with the previously explained the establishment of an accurate data information chain, CSP can clearly know building changing process and current status, and timely maintain and manage the building. Buildings are products, and products involve maintenance, repair and change of components during their use. Buildings are similar to cars in need of, regular maintenance . Building components and materials have different lifecycle, as time changes and usage condition, components will show natural or man-made changes. CSP focuses on long-term maintenance of construction products and components replacement, including the replaceability of components when there is a functionality change of the building.

## 4.5 CSP platform conception

Nowadays the platform thinking is popular. All industries are trying to find resource integration and innovative development opportunities from platform concepts. The connection between ideas, technology, market and profits is the essential foundation of platform establishment. Under market economy, mutual benefits, mutual development and coexistence are the core elements for platforms to attract many enterprises.

CSP covers all aspects of construction sector, involving system projects in every phase: system establishment, system integration, technology R&D, standard establishment, pilot demonstration, policy guidance, promotion and application, etc. CSP seeks to build a multi-layer open platform, under the guidance of policies; using point-to-area orderly procedure which means to achieve the goals of system research, industry interconnection and win-win.

### 4.5.1 Open system research platform

After years of exploration and practice, CAG gradually specifies CSP development direction. Using modern technology means to establish a thorough technology system and full service implementation system. In order to make the system construction more scientific, reasonable and perfect, under the unified technical path and standard guidance, CSP set up an open system research platform to domestic and foreign insightful enterprises, universities and research institutions. Strong cooperation, complementary advantages, mutual development and joint ownership are the advantages of CSP system research platform.

### 4.5.2 Open industry connection platform

The core element of CSP is connecting the formerly independent and scattered single technology, technique, stage, etc. as a mutually collaborated, mutually supported and mutually constrained entirety. The connection and communication of all phases: construction design, component production, system delivery, installation, operation management, etc should be realized, so that achieve goals of efficient production, rapid construction, high quality housings, high quality service, etc. Under the standard certification system framework, CSP sets up an open industry connection platform for various industries including construction, manufacturing, logistics, service, insurance and finance, etc. It provides support for enterprises connected production, connected service and connected assurance. It also provides pathways for industry structural transformation, provides platform for industry integration and coordinated development.

#### 4.5.3 Open win-win platform

CSP system housing construction is completed with the supports of a full service system: overall planning, integrated design, connected manufacturing, integrated construction and system maintenance. It offers connected business opportunities for many enterprises including design, production, logistics, construction, service, certification, insurance and finance, etc. Connected technology brings together connected products, connected enterprises, connected services and connected markets and profits. This is a win-win platform built under unified technology path, standard and certification system. In this platform, resources are shared, responsibilities are shared and profits are shared.

## Summary

With the support of modern digital information technology, equipment technology development is revolutionary. The rapid speed, wide coverage and large impact is beyond imagination. It not only changes traditional production model, increases production efficiency, expands production sector, realize the digital high-speed integration connection of all stages, enterprises and industries, more importantly, it also changes the way of thinking, way of working and technical system that have been lasting for a long time.

CSP is a system platform established under unified standards and regulations, using standardized organization means to integrate relevant industrial resources in order to complete the whole process of construction products, from planning, to design, manufacturing, construction and maintenance. CSP fully carries out its modern technology and equipment technology advantages, using standardized production management means and intelligent manufacturing means, to realize the goals of connection technology standardization and final products customization. So that to meet more social needs and make a useful attempt to China’s construction industry modernization development.

# 5. Inner Filling Application Technology

CSP is open to the technology that is consistent with its own thinking logic, it thinks that the various technology types have their own advantages, disadvantages and adaptability, each project should be based on specific circumstances for system selection. During the system selection, the area of the project, service groups, cost requirements, etc. should be comprehensively analyzed, the functional indicators and economic indicators of each method need to be comprehensively evaluated.

Comparing with the long life of support system, inner filling system uses a flexible, variable strategy to deal with the building usage life and the rapid changes in user needs, personalized requirements. Under the condition of ensuring the fast and convenient replacement of inner filling system, the principle of separation from the support body should be maintained to avoid the negative effect on support system performance due to the changes of inner filling system. In order to meet the technical requirements of the inner filling variable strategy and the demand for industrial production, the inner filling application technology uses dry construction technology and various integrated technologies.

## 5.1 Application technology classification

CSP application technology includes two categories: equipment systems and element system (Table 9). Between them, the equipment system classification includes water supply system, drainage system, electrical system, heating system, air conditioning system, fresh air system, intelligent system; element system includes wall partition wall system, ceiling system, ground system, door and window system, equipment pipeline, wooden parts.

Table 9: Application technology classification

| Classification | Equipment System | Element System |
|---|---|---|
| Type | water supply system | partition wall system |
| | drainage system | ceiling system |
| | electrical system | ground system |
| | heating system | door and window system |
| | air conditioning system | equipment pipeline |
| | fresh air system | wooden parts |
| | intelligent system | —— |

## 5.2 Typical Application Technology

### 5.2.1Partition wall system

Partition wall system is an important part of internal filled system, it plays a role of separation, combination, guidance and transition to the space. Considering the characteristics of internal filled system and the demand of building industrialization, partition wall system should not only meet the performance requirements of sound insulation, fireproof, moisture resistance, strength, stability, etc., but should also change the operating mode of traditional interior partition walls to realize factory production, on-site assembly, easy maintenance and removal.

Through background research in the domestic and foreign partition wall markets, current domestic standards and atlas, and analysis of the domestic mainly used concrete slab, gypsum board, paper honeycomb composite slab, light steel keel gypsum board, steel mesh plaster Plate spray wall, NALC autoclaved aerated concrete slab and other wall partitions, CSP distinguishes the wall partition system as two models: factory production & on-site assembly, factory assembly & on-site assembly(Table 10). Selection of partition walls are recommended to follow the requirements of internal filled wall partitions, product proposition. Among them, the former proposes the use of light steel keel gypsum board partition, paper honeycomb composite strip partition, NALC autoclaved concrete slab wall. The latter recommends the use of the partition wall from CSP independent research and development.

Table 10: Partition wall classification

| Classification | Factory production & on-site assembly | Factory assembly & on-site assembly |
| --- | --- | --- |
| Type | Light steel keel gypsum board partition;<br><br>Paper honeycomb composite strip partition;<br><br>NALC autoclaved concrete slab wall | CSP assembled partition wall |

CSP assembled partition wall is based on a unified technical path and standards for special parts research system. The following is explained by combining three aspects of partition wall system classification, assembly, advantages.

#### 5.2.1.1Classification

According to the use of location, partition wall system is divided into three categories:

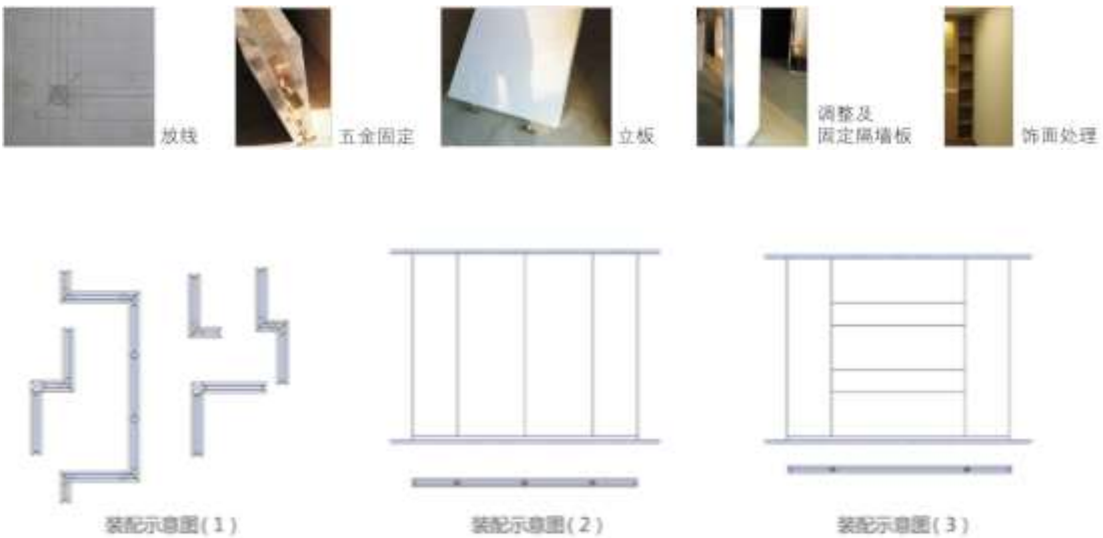
household partition wall, room partition wall, and functional partition wall (Table 11). Among them, the household partition has the property of high safety and high fire resistance, mainly for the separation of household and special function rooms; room partition has the property of general safety, and fire resistance, mainly for the separation of sub-room and functional rooms. Functional partition has the property of general safety and fire resistance, mainly for pipe closure, decorative partitions and so on.

Table 11: CSP Assembled partition classification

| Classification | Household partition wall | Room partition wall | Functional partition wall |
|---|---|---|---|
| Introduction | high safety and high fire resistance, mainly for the separation of household and special function rooms | general safety, and fire resistance, mainly for the separation of sub-room and functional rooms | general safety and fire resistance, mainly for pipe closure, decorative partitions and so on |

### 5.2.1.2 Assembly

The assembly process only needs to go through the integrated line, hardware fixed, vertical board, and adjusted and fixed partition board to be completed (Figure 14)



隔墙板 隔墙安装 拼装效果

Figure 13: CSP partition wall assembly

#### 5.2.1.3 Advantages

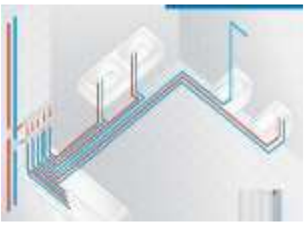
CSP partition wall system uses an assembly mode of design integration, factory production, assembly, on-site fixation. Assembly, the wall assembly efficiency, quality and accuracy can be substantial increased, for the easiness of the installation and post-replacement. The materials used can be recycled to save resources and reduce costs. Among them, the room partition wall is a composite structure that is composed of a strong thin plate, metal frame and accessories. The wall cavity is filled with heat insulation and sound-absorbing material to meet the performance requirements of different space walls; wall surface is smooth, and can be processed into a wall with different finishes in factories according to the needs of space.

### 5.2.2 Water Supply System

Water supply system is divided into two modes: parallel and series, these two definitions combined with advantages and disadvantages are explained as follows (Table 12)

Table 12: Water Supply System

| Type | Parallel | Series |
|---|---|---|
| Definition | Water supply pipes are connected from outdoor to indoor water supply separator, water supply pipe of each water usage point is directly connected from the water separator separately;<br><br>Hot water is accessed from the indoor gas water heater / electric | Water supply pipe is accessed from the outdoor, each water usage point is connected via the water supply branch pipe to the main pipe; hot water is accessed from the indoor gas water heater / electric water heater / ... , and connected via the branch pipes to each water usage point. |

| | | |
|---|---|---|
| | water heater / ..., connected to the indoor hot water separator. And then through a hot water separator separately it is connected to each water point. | |
| Illustration |  |  |
| Advantage | 1.Water pressure is stable when multipurpose water is used<br><br>2.After a single water point leaks, simply close the corresponding manifold slip and do not affect other water points<br><br>3.Minimum connector, the most secure system<br><br>4.Preferably PB pipe, the factory can complete the hot melt, pressure and testing work, only need a simple installation in the scene | 1.High market occupancy, use, installation, maintenance technology is mature and with high awareness<br><br>2. water supply pipeline commonly used in the market, low cost<br><br>3.Less space occupancy less, simple system |
| Disadvantage | 1.Less water circulation at not commonly used water point, there may breed bacteria growth;<br><br>2.High space occupation, high system complexity<br><br>3. Long pipe and high cost | 1.More pipe connection fittings, the existing domestic pipe quality, pipe fittings, installation process and other reasons make the pipe connection fittings easily have leakage<br><br>2.Water leakage point is not easy to find<br><br>3. After a single water point leaks, the inlet valve needs to be closed and water supply stops until the fix finishes. |

In addition to considering the water supply system, the pipe material, cost, etc. should also be analyzed. Selection of water supply system should follow the requirements of interior filled water supply system, product proposition, building height, market pipe quality, installation technology, cost and other conditions for a comprehensive selection.

### 5.2.3Drainage system

At present, the drainage engineering design in domestic residential buildings includes three different methods: compartment drainage, drainage under same floor and drainage after the same floor (Table 13). The compartment drainage system occupies the majority of the market, same-floor drainage is quite rare, and mostly drainage under same floor. The definition, advantages and disadvantages of three methods are explained as follows.

Table 13: Drainage system classification

| Type | Compartment drainage | Same-floor drainage | |
|---|---|---|---|
| | | Drainage under same floor | Drainage after the same floor |
| Definition | It means that the drainage pipes that accept the sanitary equipment (such as the toilet, bath, shower, etc.) are connected to the drainage riser at the next level of the installation equipment, that is, a drainage method that the drainage pipe needs to pass through the floor. | It means that the drainage pipes that accept the sanitary equipment (such as the toilet, the bath, the shower, etc.) are connected to the drainage riser at the same level of the installation equipment, that is, a drainage method that the drainage pipe does not need to pass through the floor. | |
| | | That is, the structure that needs to lay the drainage pipe will be reduced at the corresponding floor for 250 ~ 350mm, after the drainage pipes are installed, filled with lightweight materials, then install the leveling waterproof layer. | That is, horizontal pipe that accesses to sanitary equipment is installed inside the folder walls, usually build a fake wall at outside of the original folder wall, firstly install the drainage pipe, and then building the wall, the general clearance is at 150 ~ 200mm, the total thickness of the processing wall is controlled to be within 300mm.<br>95 Subject project used the combination of parts and pipes without a fake wall. It solves the |

| | | | |
|---|---|---|---|
| | | | drainage system while increasing the storage function. |
| Illustration |  |  |  |
| Advantage | 1.Low cost<br>2.higher leakage rate than same-floor drainage | 1.Clear housing property boundaries<br>2.Sanitary appliances are flexible in the bathroom area<br>3. Sound noise is low during drainage | 1.Clear housing property boundaries<br>2.Sanitary appliances use side drainage, no sanitary dead ends<br>3.Leakage reduction, easy to replace and repair<br>4.Sound noise is low during drainage<br>5.The flat structure of the floor to increase the toilet clearance height, provide a variety of possible for the space layout<br>6.Easy to clean and good for health |
| Disadvantage | 1.Unclear housing property boundaries<br>2.Drainage noise, pipeline leakage easy to have an impact on the downstairs;<br>3.Sanitary ware layout is relatively fixed, cannot be flexible changed<br>4.There are sanitary dead ends, bad smells<br>5.Iron pipe, plastic pipe and other pipes are buried under ground for a long time, due to thermal expansion and contraction, vibration | 1.Pipeline buried in the sink plate caisson, inconvenience of repair and replacement;<br>2.During the use of the bathroom, the water may penetrate into the backfilled layer, over time, there will be water in backfill layer, resulting in bad smalls.<br>3.Iron pipe, plastic pipe and other pipes are buried under ground for a long time, due to thermal | 1. High cost |

| | | | |
|---|---|---|---|
| | and other factors, the ground concrete is likely to cause cracking, influencing the use of waterproof layer, advice to use same-floor drainage. | expansion and contraction, vibration and other factors, the ground concrete is likely to cause cracking, influencing the use of waterproof layer, advice to use same-floor drainage.<br>4.Limit the clearance height of bathroom | |
| Selection | Normal | Normal | Recommend |
| Note: according to relative statistic data, the leakage rate of same-floor drainage is as high as 50-55%, leakage rate of compartment drainage is 2-5% | | | |

In addition to considering the water drainage system, the pipe material, cost, etc. should also be analyzed. Selection of water supply system should follow the requirements of interior filled water supply system, product proposition, building height, market pipe quality, installation technology, cost and other conditions for a comprehensive selection. And in accordance with the principle of visual construction, through the integrated design of construction, water supply and drainage, parts, components, the drainage system should be designed integrated.

### 5.2.4 Electrical System

The electrical system takes the lighting system as an example

CSP lighting system uses a new low-voltage lighting system (Figure 15), the lighting side only has the lighting chip and the basic steady flow part. Electric drive is generated by the central power supply, and through the low-voltage DC transmitted to the various chip side, the various parts are under overall consideration to strengthen the contact and set clear definition of work so that they can be turned into an overall control system of lighting.

The wire is laid with ribbon wire; the wiring is not buried in the main structure but directly attached to the ceiling for easy replacement, space saving and height of ceiling.

Wiring

Ultra-thin lamps

Live scene

Figure 14: Low-voltage lighting system

Low-voltage lighting system energy efficiency is very high. For the same illumination, compared to incandescent, 7W low-voltage lighting can achieve overall energy-saving efficiency of 88%, compared to energy-saving lamp, the node efficiency is 42%.

Table 14: Energy-saving Efficiency

| Low Light | 10% | 25% | 50% | 75% |
|---|---|---|---|---|
| Energy Saving | 10% | 20% | 50% | 75% |
| Lamp Life Extension | 2 times longer | 4 times longer | 20 times longer | More than 20 times longer |

### 5.2.5 Heating System

Currently, in the north of the country three heating methods are usually used: radiators, low-temperature hot water floor and sub-wall-mounted gas heating, other supplemented by central air conditioning, electric heating film and other forms of heating. The combination of advantage and disadvantages of three common heating methods are explained as follows.

Table 15: Conventional Heating System

| Type | Radiators | Low-temperature hot water floor | Sub-wall-mounted gas heating |
|---|---|---|---|
| Summary | Convection heating is dominant in China's home-use heating.When the heat medium with a high temperature flows through the heat fins, the | The heating method is to heat floor surface to a certain temperature, then relying on the heat radiation of the floor | Developed from the conventional low-temperature hot water floor heating (conventional), the thickness of |

| | | | |
|---|---|---|---|
| | heat carried by the heat medium is continuously passed through the heat fins to the lower temperature object, thereby achieving the heat transfer | to heat indoor air | conventional thin type method is about 30 ~ 40mm, by using dry construction, if the ground material is wood flooring, then skip the way of cushion layer of the warm tube. |
| Advantage | 1. Fast heating up, generally 20 to 30 minutes or so to achieve a comfortable temperature<br>2.Better than the air conditioning in terms of heating comfort and dry heating problem<br>3.The use of gas boiler as a heat source, can take into account the dual needs of hot water for heating and living<br>4.Many materials, different shapes, achieve the effect of both heating and decoration<br>5.Do not take up the high space | 1.Indoor temperature uniformity is good, large area heating, indoor temperature uniformity<br>2.The temperature gradient meets the human physiological requirements<br>3.Beautiful, hygienic, do not take up space<br>4.Good thermal stability, strong adaptability<br>5.Low maintenance costs, long use life (40 years) | 1.The overall approach to make the ground thinner<br>2.Dry construction, factory production, on-site assembly, distribution, time-saving and efficient |
| Disadvantage | 1. Comfort is worse than water/electrical floor heating<br>2.Occupy the interior space, will cause a certain impact to decoration<br>3.There is no heat source before and after heating | 1.Increase floor load<br>2.Thicker, take up space<br>3. High requirements on floor quality, continuous heating will evaporate certain gas | 1. Lifetime is about 15 years, and the updated maintenance cost is borne by the owners;<br>2. It need to keep operating at about 4 ℃ low temperature (antifreeze) when nobody at home;<br>3.There is heat pump started and flame burning, which is noisy, and air pollution problems. |

In addition to considering the heating system, the regional environment, heating pipe, cost, etc should also be analyzed. Heating system selection is recommended to be based on the requirements of filling heating system, product proposition, market pipe quality, installation process, cost and other conditions for comprehensive selection.

# 6. Indoor environmental quality

## 6.1 Introduction

Indoor Environmental Quality (IEQ) encompasses various factors that are responsible for the wellbeing and enhanced productivity of the building occupants. IEQ broadly comprises of the following aspects:

| Aspect | Description |
|---|---|
| Indoor air quality | Appreciable indoor air quality is maintained by ensuring a supply of minimum level of filtered fresh outdoor air supply free from particulate matter and spores. Fresh air is constantly needed to remove the builds up of contaminates such as carbon dioxide, radon etc. in the building interiors. |
| Indoor thermal comfort | Thermal comfort is a complex phenomenon that is affected by various indoor parameters such as temperature, relative humidity, radiant temperature, air speed and occupant parameters such as clothing and metabolic levels. |
| Indoor visual comfort | The primary objective of visual comfort is to ensure minimum levels of lighting required to carry our various activities in the space. This also includes aspects such as maximizing daylight in the space to minimize the energy consumption for artificial lighting, minimizing the glare by the use of appropriate shading elements, enabling visual connection to the exterior, and providing accessible lighting controls to the occupants. |
| Indoor acoustical performance | Acoustic quality can be improved isolating the interior spaces from external noise. In addition to the external noise, it is also important to keep interior spaces free form reverberation, noise from adjacent interior spaces, and noises emanating from building systems such as mechanical heating, cooling and ventilation and backup power generation systems etc. |
| Other aspects | Various other minor aspects also play a role in ensuring optimum IEQ such as using green and hygienic cleaning practices, pest management, and preventing tobacco smoke by designating interior spaces as smoke free zones. |

The focus of this handbook is on indoor air quality. One of the active projects in Europe on indoor air quality is the European Collaborative Action (ECA) "Urban Air, Indoor Environment and Human Exposure". ECA has been in operation for more than 25 years with the goal to provide necessary framework for realizing healthy and sustainable buildings. As part of the collaborative a team of multi-disciplinary European scientists analysed various aspects that effect indoor air quality such as thermal comfort, pollution sources, the quality and quantity of chemical and biological indoor pollutants, energy use, and the ventilation processes. A series of 28 reports have been published in different working areas covering three key aspects that form the framework:

- **Health and comfort of the occupants**. For example, report number 4: Sick building syndrome - a practical guide, report number 10: Effects of indoor air pollution on human health, report number 11: Guidelines for ventilation requirements in buildings, etc.
- **Source, evaluation and control of various indoor and outdoor pollutants**. For example, report number 1: Radon in indoor air, report number 6: Strategy for sampling chemical substances in indoor air, report number 20: Sensory evaluation of indoor air quality, etc.
- **Resource and energy conservation and sustainability issues pertaining to indoor air quality and comfort**. For example, report number 17: Indoor air quality and the use of energy in buildings, report number 23: Ventilation, Good Indoor Air Quality and Rational Use of Energy, etc.

## 6.2 Indoor air quality and occupant health

People spend most of their lives indoors and hence it is important that building interior should contribute to the comfort and wellbeing of its occupants. Unhealthy building interiors can result from the following factors and can result in what is called a 'sick building syndrome' (SBS). Sick building syndrome can be identified by various symptoms such as nasal, ocular, oropharyngeal, cutaneous and other general manifestations and possibly effect respiratory, immune, endocrine, sensory and reproduction systems. Sometimes the indoor pollutants are also carcinogenic in nature. The following factors chiefly affect the health of the occupants:

| Factors | Source/cause | Mitigation |
|---|---|---|
| Physical | Indoor temperature, humidity, lighting and | By ensuring thermal comfort through building design and |

| | | |
|---|---|---|
| | noise levels | comfort systems (cooling and heating systems) |
| Chemical | Chemical factors emanating from building interiors can be grouped into major categories: Environmental Tobacco Smoke (ETS), Glycol ethers, Volatile Organic Compounds (VOC), Biocides, odours and other gaseous substances. | By ensuring adequate ventilation levels to remove the builds up of harmful gas concentration |
| Biological | Development of mould, mites and other microbial growth | Partly by taking care of the physical factors such as humidity and partly by the general cleanliness and maintenance of the building |
| Psychological | Are varied in nature and often manifest from or result into irritation caused by other factors. They are subjective and case specific. | By mitigating all other factors |

Of interest to sustainable interior design, materials and indoor air quality are the biological and chemical factors that contribute to SBS and are emitted indoors. Of these four groups, Glycol ethers and VOC directly results from the use of interior materials. Biocides and odours result from space function, human activity and metabolism. It is vital to know more about two groups that affects the most.

| Group | Description |
|---|---|
| Ethers and VOCs | Glycol ethers<br><br>There are two types of glycol ethers. E series formed from ethylene glycol and P series formed by Propylene glycol. They are chiefly found in binding materials paints, inks, and varnishes, cleaning agents, wood based products such as particle board and plywood, urea-formaldehyde foam for insulation. They often impact reproductive health and induce hematologic toxicity.<br><br>Volatile Organic Compounds (VOCs)<br><br>They consist of glycol ethers and other organic chemicals with high vapour pressure at room temperature. They are chiefly found in furniture, flooring materials paints and protective coatings. They impact sensory, respiratory, immune systems and are known to be cariogenic. |

| | |
|---|---|
| Biocides and odours | This category includes gases such as carbon dioxide, carbon monoxide, nitrogen dioxide, ozone and sulphur dioxide that eliminate as a result of human metabolism. |

### 6.2.1Assessing indoor air quality

Indoor air quality is assessed differently for contaminates emerging from Ethers and VOCs and Biocides and odours. While the former are harmful in their minutes concentrations, the latter are acceptable to much higher concentrations. Therefore, their assessment and subsequent mitigations methodologies are slightly different. This section discusses how to assess indoor air quality and the next section discusses the mitigation methods.

#### 6.2.1.1 Ethers and VOCs

One of the key aspects to find the source of the pollutants is to draw a list of compounds and their concentrations that are perceived to negatively impact human health. For this purpose, Lowest Concentrations of Interest (LCI) approach has been followed for assessing the health effects of compounds emitted from various construction materials. A harmonization process called EU-LCI has been undertaken in Europe to provide a protocol for establishing list of compounds and their associated EU-LCI values. An EU-LCI working group has been constituted "to derive and recommend EU-wide harmonised health-based reference values for the assessment of product emissions, based on the so-called 'Lowest Concentration of Interest' (LCI) concept". LCI concept is defined as "the lowest concentration above which, according to best professional judgement, the pollutant may have some effect on people in the indoor environment".

EU-LCI is evaluated based on the definition-" EU-LCI values are health-based reference concentrations for inhalation exposure used to assess emissions after 28 days from a single product during a laboratory test chamber procedure as defined in the Technical Specification TS 16516 of the horizontal testing method developed by CEN TC 351/WG 2" . EU-LCI values are usually expressed as $\mu g/m^3$. In order to promote the transparency in developing EU-LCIs a data compilation sheet and fact sheet have been developed listing all relevant toxicological data, general information, assessment factors and the derivation of the EU-LCI value. An interim list of EU-LCI values for various compounds has been made within a flexible framework to enable future revision of the list and the values.

#### 6.2.1.2 Biocides and odours

Carbon dioxide buildup in the space is often used as a surrogate to assess the builds up of all kinds of biocides (not including ethers and VOCs) within the space. This applies to typical home and office spaces. Outdoor air carbon dioxide concentration is in the range of 250-350 ppm, usually. Although, the strict $CO_2$ concentration and their effect vary in different technical studies, $CO_2$ concentration in typical occupied spaces with good fresh air exchange is in the range of 350-1,000 ppm. Concentrations in the range 1,000-5,000 although do not pose severe health risks, they produce varied degree of inconveniences such as drowsiness, headaches, stale and stuffy air etc. as a result of poor air. For practical purposes and in most jurisdictions 5,000 ppm is taken as the workplace exposure limit, considering an 8 hour Time Weighted Average (TWA).

ASHRAE Standard 62.1 suggests that $CO_2$ concentrations less than 700 ppm above that of the outdoor air concentrations is likely to satisfy comfort criteria with respect to bio effluents. At an outdoor baseline $CO_2$ concentration of 300 ppm an air change rate of 15 cfm/person ensures a 1,000 ppm (1.8 g/m$^3$) value in the interior space. Different standards and guidelines have different values for the safe and permissible $CO_2$ concentrations and the caveats have to be interpreted accordingly. The following figure shows different concentrations of $CO_2$ based on different ventilation levels. Although higher ventilation levels are highly welcome, they also tend to increase energy consumption as well. Therefore, this balance has to be maintained which will be discussed in the subsequent sections.

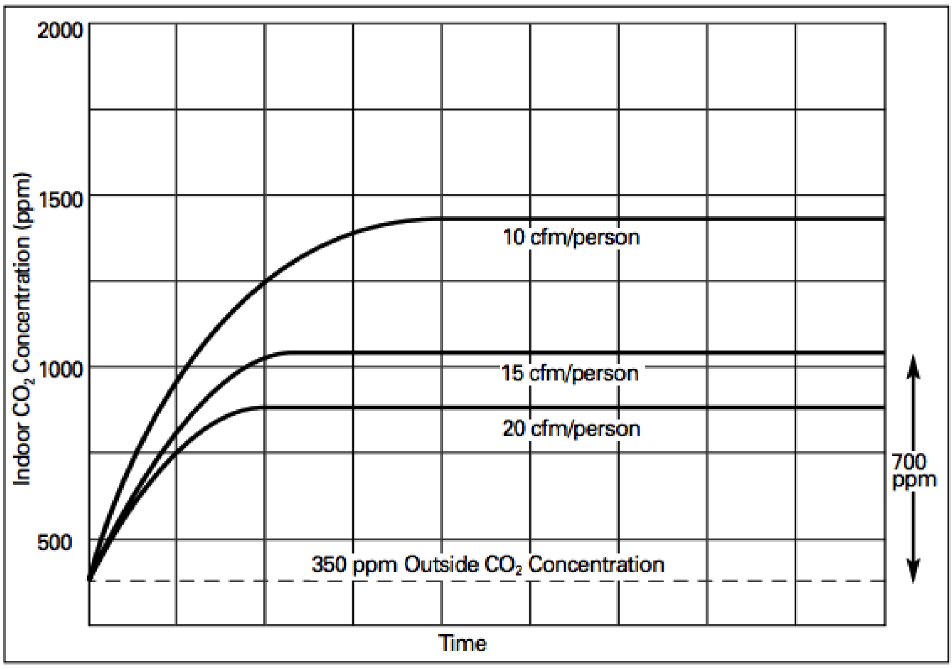



Figure 15: Equilibrium of CO2 Concentration at Various Ventilation Rates

In order to measure the $CO_2$ concentration levels in the space $CO_2$ sensors/monitors are placed within the occupied spaces between 3-6 feet. Sometimes these monitors are also placed near the return air grill of the mechanical ventilation systems that serves as a proxy for the $CO_2$ concentration within the space. These sensors typically relay the information to the mechanical ventilation systems signalling the increase in the outdoor fresh air into the system. This is called demand-controlled ventilation and is one way to ensure adequate ventilation levels and at the same time optimize energy consumption.

## 6.3Ensuring indoor air quality

An appreciable level of indoor air quality is maintained by lowering the concentration of indoor pollutants. The concentration of indoor pollutants can be controlled by two important measures.

1. **Minimizing source of pollutants such as ethers and VOCs: Prior to construction** - The first measure is to select appropriate interior materials and components (containing ethers and VOCs) so as to minimize the source of pollutants to the minimum concentration levels possible.
2. **Providing adequate ventilation:** This again consists of two parts:

- **Post construction and before occupancy** - The first part of the second measure is to ensure adequate ventilation levels necessary to remove the high concentration of pollutants immediately after their installation and before occupancy (applicable to Ethers and VOCs).
- **Durign occupancy** – The second part of the second measure is to ensure adequate ventilation levels necessary to dilute the pollutants to acceptable levels over the usage period of the interior space (Majorly applicable to Biocides and odours and to a minor extent to Ethers and VOCs).

### 6.3.1 Minimizing pollutants such as ethers and VOCs

**Sustainable approach for interior material selection prior to construction**

There are tons of interior building materials available: Some of these materials, products and methods are hazardous to soil, air, ground- and surface water and can also affect the health of humans, flora and fauna negatively. It is necessary to reduce and avoid the influence of such materials on soil, air, ground- and surface water, DGNB invented an approach to reduce risks to humans and the local environment. The material selection approach refers mainly to materials, products and methods that cause short-, medium, - and long-term damage to soil, air, ground- and surface water as well as humans, flora and fauna.

In addition, as discussed above, it is also absolutely necessary to reduce and limit the VOC (volatile organic compounds) and glycol ether (e.g., formaldehyde) content in materials, products and methods. This leads to reduce the emissions and out gassing of such VOCs inside offices, residential buildings and other (building) objects and ensure users and environments health.

The development in the IAQ research and increased awareness on its impact on public health has resulted in the development of IAQ labelling schemes either by government agencies or NGOs. Different countries have different focus and approach for classification based on TVOC, odour, LCIs and have different means of labelling, for example, in quality class groups, in time-value (days), and binary (Accepted – Yes/No). Most of the labelling products have started as voluntary systems, for example in Finland and Denmark, with some of them transforming into mandatory systems, for example in France. A harmonization framework has been proposed in ECA report number 27 with the aim of converging existing mandatory and voluntary labelling schemes in EU.

Examples for IAQ labelling include “GEV-EMICODE” for flooring installation materials with very low emission, “Blue Angel RAL-UZ 102” for indoor decoration paints with very low emission etc .

**GEV-EMICODE: EMICODE** labelling system shows ether and VOC emission content of adhesives, sealants, parquet varnishes and other construction products. There are three emission classes: EC2 (low emissions), EC1 (very low emissions), and EC1 PLUS (very low emissions PLUS) based on laboratory testing.

EMICODE EC 1 and EMICODE EC1PLUS labelled flooring adhesives cover about 80-90% market share of all flooring installation adhesives in Germany.

**Blue Angel RAL**:Blue Angel is the oldest ecolabel in the world, covering some 10.000 products in about 80 product categories. Blue Angel mostly covers German market. Use of Blue Angel requires an application to RAL. There are a number of Blue Angel criteria for products with low emissions into indoor air. For example, "Blue Angel RAL-UZ 102" for indoor decoration paints requires very low solvent and formaldehyde content; amount of softeners under 0.1 %; preservatives reduced to a minimum.

The following are few controlled test methods and labels for construction products popular in Europe:

- AgBB scheme (emissions testing)
- Blue Angel - RAL UZ for building construction products construction (emissions testing)
- TÜV testing (emissions testing)
- IBR and IBN checked (building biological testing and emissions testing)
- Nature Plus (emission testing, ingredient testing)
- Emicode - EC1 (formaldehyde emissions testing procedures for glue and installation materials.)
- E1 and E1plus - (emission test procedure for formaldehyde for wood and timber materials)
- Other country-specific test methods

The following table shows the requirements to meet these criteria in various green building standards. These credits ensure source control of Ethers and VOCs, that is, low ether and VOC emitting materials are selected for interior construction and furniture. The selection procedure and adhering standards vary depending on the rating system.

| Green building rating system | Requirement for materials |
|---|---|
| LEED Interiors | LEED awards credit points for keeping in VOC emission in check as a part of its Indoor Environmental Quality credits. The compliance can be achieved by two options, either by emission and content standards for different individual materials categories or assemblies.<br><br>For general emissions evaluation, building products must be tested must be tested and determined compliant in accordance with California Department of Public Health (CDPH) Standard Method v1.1–2010. The range of total |

| | |
|---|---|
| | VOCs after 14 days (336 hours) measured as specified in CDHP Standard Method v1.1 should be classified into three categories: less than 0.5 mg/m$^3$ or less; between 0.5 and 5.0 mg/m$^3$; or 5.0 mg/m$^3$ or more.<br>Onsite wet applied products such as paints and coats, adhesives and sealants must meet the applicable VOC limits as per specified standards such as the California Air Resources Board etc.<br>Composite wood should be documented not to exceed a concentration limit of 0.05 ppm of formaldehyde (0.06 mg/m$^2$-h) when tested as per specified standards such as E-717:2004 etc . |
| BREEAM UK Refurbishment and Fit-Out 2014 | TVOC concentration is measured post construction (but pre-occupancy) and found to be less than 0.30/m3 over 8 hours, in line with the Building Regulation requirements."<br><br>In addition, BREEAM also has VOC specifications on building products. It lists eight product categories, at least five of which should meet the testing requirements and emission levels for VOC emissions against the relevant standards. |
| DGNB - German Sustainable Building Council | DGNB single-family house mentions that TVOC should be in the range of 0.2-0.3 mg/m$^3$ while formaldehyde should be 0.1 ppm among other ethers and VOCs.<br><br>All composite wood, wet coatings used in paints, finishes, lacquer, sealants, and in addition, polyurethane, bituminous, plastic, oil and wax products should be adhered according to relevant GISCODE standard.<br><br>In general, all VOC/formaldehyde content of indoor-/outdoor paints should be according RAL-UZ-guideline ("Blue Angel Label"); and all VOC/formaldehyde content of adhesives such as silicones, carpet glues, epoxy products, etc. according RAL-UZ-, GEV-EMICODE- or GISCODE-guideline |
| Chinese Green Building Rating System | The indoor air quality should follow the Indoor air quality standard (GB/t18883). TVOC should not be higher than |

| | |
|---|---|
| | 0,60mg/$m^3$ |

Besides the indoor air quality labelling, products are also often certified with labels indicating that the materials have low environmental impact. For example, GreenBookLive by BRE Global, which also manages the BREEAM sustainable building rating maintains a database of third party verified environmentally friendly construction products.

### 6.3.2 Selecting interior materials wisely – an example of DGNB system

Here DGNB system will be presented as an example to illustrate how to wisely select building materials, products, and application methods to reduce risks to humans and the local environment. As discussed above, the specific aim for secure indoor air quality is to reduce and limit the VOC (volatile organic compounds) and glycol ether (e.g., formaldehyde) content in materials, products and methods.

Box 1: DGNB system

| |
|---|
| The DGNB System (Deutsche Gesellschaft für nachhaltiges Bauen; German Sustainable Building Council) covers the key aspects of sustainable buildings: Environmental, economic, sociocultural and functional aspects, technology, processes and site. It assesses buildings and urban districts which demonstrate commitment to meet sustainability objectives. The assessments are based on the entire life-cycle of a building, but especially on the wellbeing of the users. The DGNB system does not assess individual measures, but instead the overall performance of a building or urban district. |

#### 6.3.2.1 Methodology

Indoor Air Quality is also a key criteria of DGNB system: Measurement of TVOC emissions ensures good indoor air quality by minimizing VOC emissions.

**Planning procedure**

Beginning with the early planning stage of a construction project, the critical substances of certain materials, products and methods must be considered and verified according to DGNB requirements. The following building components need to be considered:

- Floor structure including foundations
- External wall structure
- Internal wall structure
- Ceiling structure

- Roof structure
- Underground car parks (are considered separately)

All materials and components that have to be considered are specified and explained in DGNBs material catalogue. There are 4 quality classes for each material or components with different threshold requirements (Table 16). Table 17 gives an example of products with different quality levels.

Table 16: Product Quality Classes (DGNB)

| Quality classes | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | J | K |
| | Relevant component/ Building material/ Surface | Area | Materials considered/ Aspects | Relevant Standard (Footnote ) | Quality class 1 | Quality class 2 | Quality class 3 | Quality class 4 | Documentation Type | Scope |
| | Where is this specifically applicable? | Product Type | Explanation | | Limit Value –10CLP | Referenc e–50 CLP | Partial Objective –100 CLP | Target value – 100 CLP | Evidence require for each aspect | Requirement applies to the following items |
| Legally valid evidence of equivalence with any of the listed standards, references or labels will be recognised in relation to the relevant substance (column A) | | | | | | | | | | |
| 1 | Coatings on non-mineral backgrounds: Metals, wood, plastics | Liquid coating materials are meant: Decorative lacquers/gla zes with primer coatings Effect coatings (e.g. metallic | VOC | VOC-definit ion according to Directive 2004/42/E C | < 300 g/l– categor y D accordi ng to RL 2004/4 2/EC | Water schedule products in accordanc e with the current Decopaint Directive | < 100 g/l or RAL-UZ 12 a | RAL-UZ 12 a | TM + SDB + manufacturer declaration/test certificate | All relevant components and building products |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | paints) are an exception on this | | | | | | | | |
| 2 | Coatings on primarily mineral backgrounds such as concrete, masonry work, mortar and putty (including open pore putty), plasters and wallpapers, titles, plasterboard etc. Floor surfaces with special resistance requirements (such as OS systems) and traffic routes such as underground car parks, access roads, etc. are taken into consideration | Decorative paints, decorative fillers, dust-laying coatings, ground coatings (e.g. deep round) floor coatings without special resistance requirements, concrete protective coatings | VOC/SVOC | VOC-definition according to Directive 2004/42/EC | Water soluble products in accordance with the current Decopaint Directive | < 30 g/l | Free of solvents and plasticisers in accordance with VdL-RL01 or RAL-UZ 102 (SVOC) | Free of solvents and plasticiers in accordance with Vdl_RL01 or RAL-UZ 102 (SVOC) | TM + SDB + Manufacturer declaration/test certificate | All relevant components and building products<br>No documentation is required for max. 5 % of the GFA according to DIN 277. |

Table 17: Example of products with different quality levels

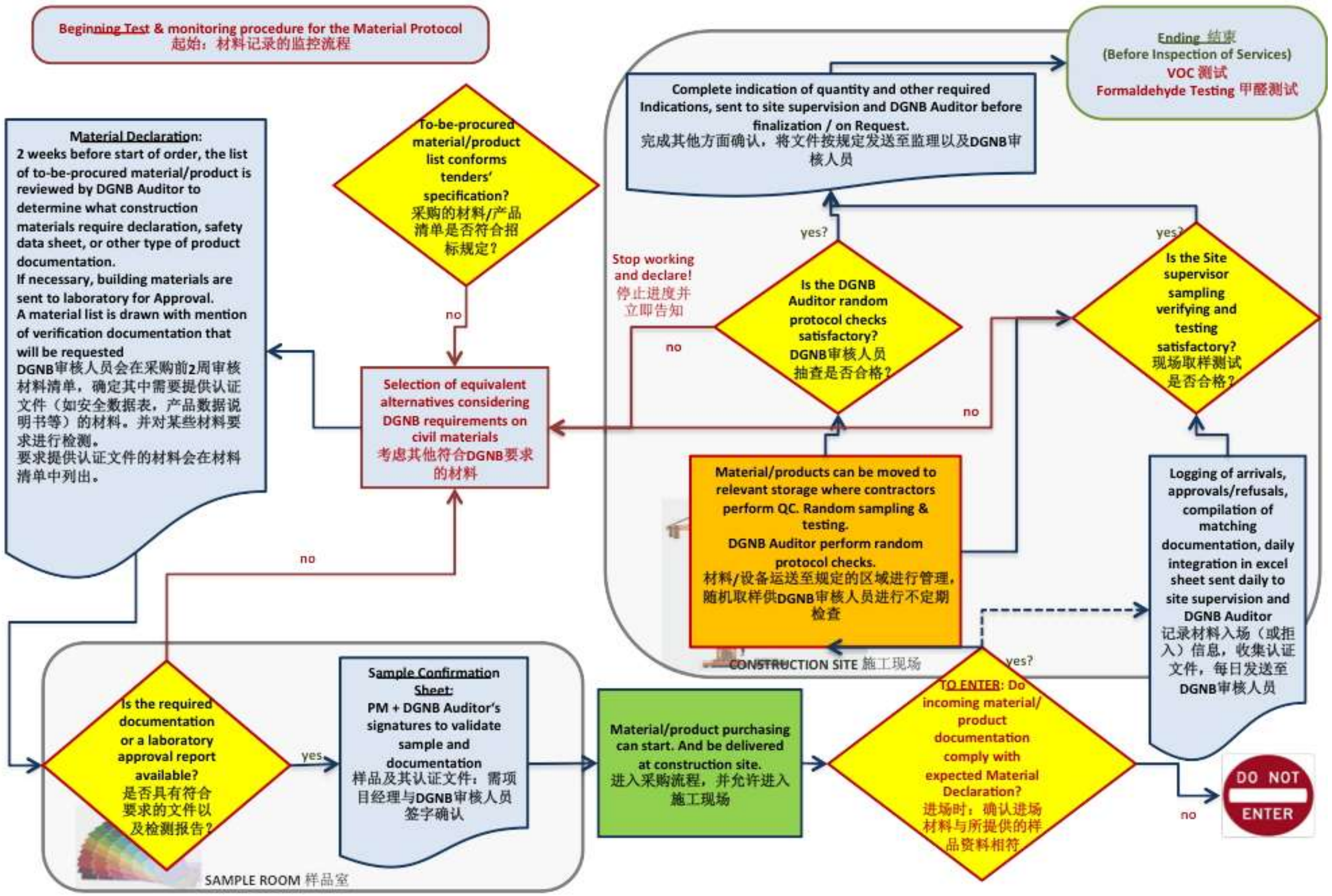
| Nr. | Material type<br>All material docs should include sample acceptance sheet and MSDS | GB50325-2010 limit OR test following local GB/T standard with DGNB limit or _LEED | Quality level 1 | Quality level 2 | Quality level 3 | Quality level 4 |
|---|---|---|---|---|---|---|
| 1 | Indoor coating on non-mineral surfaces (metal, woods, plastic), not include effect coating:<br>Wood lacquer | Test for TVOC/ Formaldehyde emissions after 24h, 72h | VOC < 300g/l:<br>Dulux wood lacquer, water-based: 160RMB/L | Water dilutable products | VOC < 100g/l:<br>_LEED | RAL UZ 12a<br>Product with the Blue Angel Label (RAL UZ 12a*) or equivalent<br>Water based acrylic lacquer Schulz Farben: 300 RMB/L |
| 2 | Indoor coating on mineral surfaces (concrete, masonry, mortal, plaster and wallpaper, textile, plasterboard etc.):<br>Interior coating | | Water dilutable products:<br>Dulux: 20-40 RMB/L | VOC < 30g/l:<br>_LEED | RAL UZ<br>102<br>Product with the Blue Angel Label (RAL UZ 102) | Product with the Blue Angel Label (RAL UZ 102) or equivalent<br>Interior Wall Paint PS143 Schulz: 100-150 RMB/L |
| 3 | Outdoor coating on mineral surfaces (concrete, masonry, | HJ/T 201-2005<br>GB24408-2009 | Water dilutable products with VOC <40g/l | Water dilutable products with VOC | Water dilutable products with VOC | Water dilutable products with VOC <40g/l |

| | | | | | | |
|---|---|---|---|---|---|---|
| | mortal, thermal insulation, façade wall paper, plasterboard, etc.) | JG/T210-2007<br>Water-based primer:<br>VOC <120g/l<br>Water-based coating:<br>VOC <150g/l | VOC <40g/l | <40g/l<br>VOC <40g/l | <40g/l<br>VOC <40g/l | VOC <40g/l |

General requirements for products painted or applied on-site include:

- VOC/formaldehyde content of indoor-/outdoor paints according RAL-UZ-guideline ("Blue Angel Label")
- VOC/formaldehyde content of adhesives such as silicones, carpet glues, epoxy products, etc. according RAL-UZ-, GEV-EMICODE- or GISCODE-guideline
- Materials that are prepared off-site require need to follow additional requirements:
- Requirements for VOC and heavy metal relating to components painted, varnished or lacquered off-site (e.g. steel structures, doors, frames, radiators etc.)
- Requirements for halogenated propellants relating to foam insulating materials
- Requirements for VOC and biocide agents for pre-treated timber components
- Requirements for treatment with Cr(VI) compounds relating to aluminum and stainless steel components
- Lead, cadmium and zinc stabilizers relating to plastic windows, floor- and wall coverings
- Figure 17 gives an overview of the different steps of selecting building materials and components based on DGNB system.

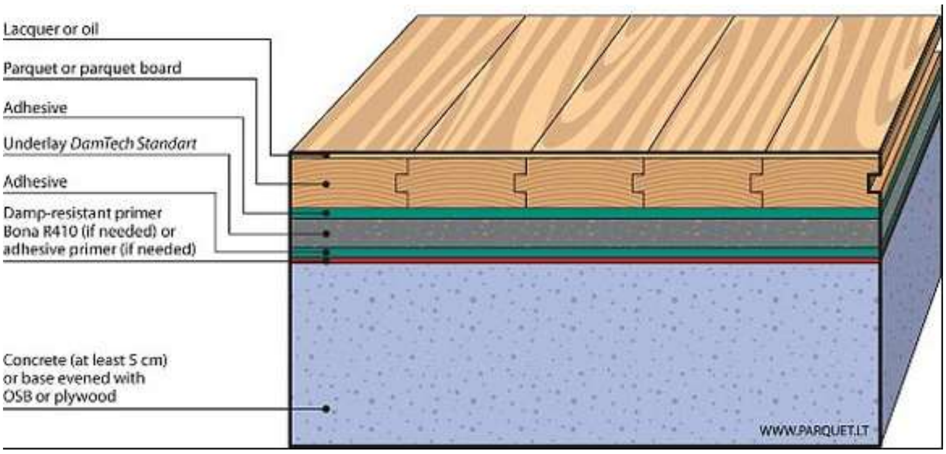
Figure 16: Overview of the procedure



### 6.3.2.2 Material Tracking

A comprehensive layer diagram including auxiliary materials such as adhesives, primers etc. needs to be provided for each of the building components. Figure 18 shows an example of such a layer diagram.

Figure 17: Layer diagram for building components (parquet




For each material, product and method used, comprehensive and verifiable evidence must be collected. Suitable data sources include:

- Technical information
- Safety data sheets (MSDS)
- Environmental product declarations and manufacturer declarations on contents and formulation components
- Manufacturer declarations
- Table 18 shows material tracking information for each of the materials in total building components.

Table 18: Material tracking iformation in total building components

| General Information | | | | | |
|---|---|---|---|---|---|
| | Chinese | Chinese | Chinese | | Chinese |
| No. | Project unified code | Material Name | Brand in Contract | Status | DGNB requirement |
| 12 | MA_ID_012 | Bamboo Veneer<br><br>Chinese | WV-01 Da Zhuang<br><br>Chinese | OK | |
| 12.1 | MA_ID_012.1 | Bamboo Veneer Glue<br><br>Chinese | Mapei<br><br>Chinese | OK | Certified environmental label: EmiCode (EC1/EC1plus), Der Blaue Engel (RAL-UZ 113) |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | Chinese |
| 12.2 | MA_ID_012.2 | Lacquer paint<br>Chinese | Schulz<br>Chinese | OK | Chinese<br>UZ<br>Chinese<br>Product with the Blue Angel Label (RAL UZ 12a*) or equivalent |

| DGNB Verification | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Nr. | Chinese<br>Comments | Chinese<br>Threshold value | Chinese<br>DGNB quality level | Chinese<br>Sample (Y/N) | Chinese<br>EDS Approval Date | Chinese<br>Idealsun Approval Date | Chinese<br>German Centre<br>Approval Date | Chinese<br>VA Approval Date |
| 12 | Please include all auxiliary in material protocol according to sample 150806_GCT _1.6_Material Tracking Table_0X.<br>Provided. | | - | Need to prepare | 10/12/2015 | 9/18/2015 | 10/14/2015 | 9/17/2015 |
| 12.1 | Provided. | | 4 | | 11/17/2015 | 11/25/2015 | 11/25/2015 | 11/25/2015 |
| 12.2 | Provided. | | 4 | | 11/17/2015 | 11/25/2015 | 11/25/2015 | 11/25/2015 |

**6.3.2.3 Material Approval**

For each material, product and method a material approval sheet is created, signed by all relevant parties of the project (Figure19).Together with material documentation the documents are comprehensible and submitted for certification.

样品确认单

| | | | |
|---|---|---|---|
| 编号 | | 封存日期 | |
| 样品名称 | | | |
| 颜色 | | | |
| 型号、规格 | | | |
| 厂家名称 | | | |
| 使用方位 | | | |
| 样品照片 | | | |
| 总包工程师签名 | | | |
| 业主工程师签名 | | | |
| DGNB 代表签名 | | | |
| 业主代表签名 | | | |

Figure 18: Example of material approval sheet

#### 6.3.2.4 Feasibility of DGNB material selection system in China and challenges

Generally, products with the Blue Angel label or EMICODE are not common in China. Except for imported products, there are not such local labels that are comparable. Local standards cannot contribute directly to the requirements of Blue Angel or EMICODE because the threshold setting that is not based on the same type of results . Table 19 shows various Chinese standards and the difference with Blue Angel label and EMICODE.

Table 19: Chinese standards in comparison with Blue Angel and EMICODE

| Chinese Standard | Product Group | TVOC-Emission Test | VOC content Test | Formaldehyde content Test | Are EMICODE requirements fulfilled? | Are Blue Angel requirements fulfilled? |
|---|---|---|---|---|---|---|
| GB 18582-2008 | Indoor refurbishing and decorating materials (interior architectural coatings) | No | Yes | Yes | - | Formaldehyde/ VOC |
| GB 24410-2009 | Indoor refurbishing and decorating materials (water based woodenware coatings) | No | Yes | Yes | - | Formaldehyde/ VOC |
| HJ 2537-2014 | Technical requirements for environmental labelling (water based coatings) | No | Yes | Yes | - | Formaldehyde/ VOC |
| GB 18583-2008 | Indoor refurbishing and decorating materials (adhesives) | No | Yes | Yes | TVOC | TVOC/Formaldehyde |
| HJ/T 220-2005 | Technical requirements for environmental labelling (adhesives) | No | Yes | Yes | TVOC | TVOC/Formaldehyde |
| GB 187597-2001 | Indoor refurbishing and decorating materials (carpets, carpet | Yes (after 24 h) | No | yes | TVOC | TVOC/Formaldehyde |

| | | | | | | |
|---|---|---|---|---|---|---|
| | cushions and adhesives) | | | | | |
| HJ/T 220-2005 | Technical requirements for environmental labelling (carpets adhesive) | Yes (after 24 h) | No | yes | TVOC | TVOC/Formal dehyde |
| GB 18580-2001 | Indoor refurbishing and decorating materials (formaldehyde emission of wood based panels and finishing products) | No | No | yes | - | TVOC/Formal dehyde |
| HJ 571-2010 | Technical requirements for environmental labelling (wood based panels and finishing products) | Yes (after 72 h) | No | yes | - | TVOC/Formal dehyde |
| GB/T 5849-2006 | Blockboard | no | No | yes | - | TVOC/Formal dehyde |

However, in China the main labeling for products such as paints or adhesives is the China Environmental Labeling – 10 circles label. The range of products being certified by this label grows and is adapted to the ISO norms. More and more products categories are certified according to this label.

**Proposed adaption for German Centre, Qingdao project for DGNB certification**

Because of the differences in Chinese testing methods and the requirements by DGNB, an approach to request additional VOC emission testing was proposed for the German Center project in Qingdao.

The case study is a waterproof coating which could not achieve higher quality level than level 2, due to the missing VOC emission test required according to the EMICODE-guideline. The guideline which this product relates to is Chinese GB 18583-2008 “Indoor decorating and refurbishing materials – Limit of harmful substances of adhesives”. No VOC emission test is implemented here. Thus, in order to achieve high score in this project, the waterproof coating was tested according to standards developed for carpets (GB18587-2001 Indoor refurbishing and decorating materials (carpets, carpet cushions and adhesives)), where the necessary method for VOC emission testing is included.

The company WESSLING CONSULTING SHANGHAI LTD. was consulted for a proposal to conduct additional testing. WESSLING can provide testing standards according to international guidelines to make sure the thresholds are comparable with DGNB. However, the client decided not to pay additional for testing, but chose another product that could fit the DGNB requirements.

The intention to apply the proposed testing method to other Chinese guidelines can also push the development to implement VOC emission testing in Chinese guidelines in a wide range. Especially for adhesives from Chinese suppliers this can ensure the comparability to DGNB requirements.

**Proposed adaption for German Centre, Taicang project**

If VOC emission testing is existing for related standards of a product, then the evaluation of VOC should be done after the values given by the Chinese test results compared with Blue Angel/EMICODE thresholds. This means:

- If VOC emission results e.g. after 3 days according to Chinese guidelines are already lower than after 3 days according to EMICODE or Blue Angel, it can be validated as passed according to EMICODE or other related standards.
- If VOC emission results e.g. after 2 days according to Chinese guidelines are lower than after 3 days according to EMICODE or Blue Angel it can be validated with a conservative scoring of 30%.

In fact, the project management’s approach was to use products that can contribute to a higher quality level as level 1, for example, the interior paint is a product with the Blue Angel label.

**Lessons from this project include**:

- Requirements on paints, adhesives and other fit-out materials have been set in tenants’ handbook.
- By doing this it can be ensured that the fit-out offices fulfil the requirements needed for DGNB in terms of later VOC emission testing.

- Permanently on-site checks were conducted to ensure material verification and approval.
-

### 6.3.3 Providing adequate ventilation

### 6.3.4Post construction and before occupancy

It is important to ensure adequate ventilation levels necessary to remove the high concentration of pollutants immediately after their installation and before occupancy especially to dilute Ethers and VOCs.
This is done by ventilating the spaces at high ventilation rates for days or weeks. The rate of ventilation and the duration of ventilation depend on the standard being used. For example, LEED systems offers three paths for compliance one of which is to flush out the building by supplying a total air volume of 14,000 cubic feet of outdoor air per square foot of floor area at an internal temperature of 15° C, and at a relative humidity not exceeding 60% where mechanical cooling is also being operated.

### 6.3.5 During occupancy

Adequate amount of ventilation is required indoors to remove the carbon dioxide build up in the space, remove unpleasant odours and other metabolic gases, dilute harmful substances such as glycol ethers and VOCs.
Standard EN 15251 defines various IEQ parameters including indoor air quality and specifies calculation procedures of minimum ventilation levels required for various building type and occupancy patterns. These standards are applied for mechanically ventilated buildings, as ventilation patterns in naturally ventilated buildings are quite erratic.
The following table provides an idea of the acceptable ventilation rates in residential buildings in few European countries:

Table 20: Acceptable ventilation rates in residential buildings in European countries

| Country and Standard reference | Whole Building Ventilation Rates | Living Room | Bedroom | Kitchen | Bathroom + WC | WC only | Standard |
|---|---|---|---|---|---|---|---|
| Brussels (NBN D 50-001) | 3.6 $m^3/(h\ m^2)$ floor surface area | Minimum 75 $m^3/h$ (limited to 150 | Minimum 25 $m^3/h$ (limited to 72 $m^3/h$) | Open kitchen Minimum 75 $m^3/h$ | Minimum 50 $m^3/h$ (limited to 75 $m^3/h$) | Minimum 25 $m^3/h$ | Requirement |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | $m^3/h$) | (exhaust) | | | | |
| Denmark (BR10) | Minimum o.3 l/(s m²) (supply) | Minimum 0.3 l(s m²) (supply) | 20 l/s (exhaust) | 15 l/s (exhaust) | 10 l/s (exhau st) | Requireme nt |
| France (Arrêté 24.03.82) | 10-135 $m^3/h$ (depending on the room number and ventilation system) | | Continuo us 20-45 $m^3/h$ | | Minimu m 15 $m^3/h$ | Requireme nt |
| Germany (DIN 1946-6) | 15-285 $m^3/h$ | | 45 $m^3/h$ (nominal exhaust flow) | 45 $m^3/h$ (nominal exhaust flow) | 25 $m^3/h$ (nomin al exhaust flow) | Recommen dation |
| Italy (Legislative Decree 192/2005, Uni EN 15251) | Naturally ventilated 0.3 – 0.6 vol/h | 0.011 $m^3/s$ per person for an occupancy level of 0.04 persons/$m^3$ | | 4 vol/h | | Recommen dation |

The calculation procedures for commercial buildings depend on the following factors:

- Space typology
- Type of mechanical ventilation system
- Occupant density
- Area

Standards such as EN 16798-3, ASHRAE 62.1 etc. specifies calculation procedures for performance requirements for ventilation and room-conditioning systems based on the factors mentioned above.

**Energy efficient ventilation**

Mechanical ventilation systems are either standing alone simple ventilation systems or often a part of cooling and heating systems and tend to consume energy for their operation. The fresh supply air introduced into the space from outside also contributes to convective cooling or heating energy. Therefore, it is vital to ensure that adequate ventilation is maintained while consuming minimum energy possible.

Report number 17 and 23 of ECA provides guidelines on rational use of energy and yet maintain good indoor air quality and ventilation standards. Air Infiltration and Ventilation Centre (AIVC) published a guide - GV: A Guide to Energy Efficient Ventilation laying emphasis on various efficient ventilation strategies at optimum cost. BUILDING ADVENT project has documented energy efficient ventilation systems in 18 non-domestic buildings. The purpose of the project was to support the implementation of low energy ventilation systems and promote dissemination of good practice examples.

The following measures can be taken to ensure energy efficient ventilation:

- **Use of energy/heat recovery systems:**

  **Energy recovery systems can recover 60-90% of the heating or cooling energy that is stored in the exhaust air. This reduces the need to use energy for heating or cooling the supply air accordingly which otherwise is vented out of the building in the form of stale/return air.**

  By using Energy Recovery Ventilators the heat/cold from the return air can be exchanged with the fresh air that is drawn in into the system, thereby preheating/precooling the fresh air and thus reducing the ventilation load on the system. Popular technologies are thermal wheel type heat exchanger with a typical efficiency of 65 %-75 % and a maximum of 90 % and flat plate heat exchanger with a typical efficiency of 50 %-65 % with a maximum efficiency of 70 % (Carbon Trust). However, the efficiency does not only depend on the ERV systems but also on other factors like ventilation rate etc.

- **Demand control ventilation using CO2 sensors:**

  **Studies show that by employing demand control ventilation energy savings of up to 40% can be obtained (Pavlovas, 2004; Becker, Bollin & Eicker, 2010).**

  Minimum levels of ventilation are required in space for fresh air requirements both for breathing and to maintain optimum humidity levels. Various standards and guides like ASHRAE 62.1-2010, CIBSE Guide E, describe the minimum acceptable ventilation levels (for more on ventilation see Ventilation). Ventilation in the building can be optimized effectively through a strategy known as demand control. This strategy calculates the amount of required ventilation by sensing the amount of carbon dioxide (CO2) and humidity in the space. CO2 sensors and humidity sensors are placed either in the space or in the return air duct. They measure the amount of CO2 and humidity present in the space and thereby adjust the ventilation rate accordingly. This enables reduction in the conditioned load of the fresh air by reducing the fresh air quantity and at the same time maintaining minimum fresh air levels. This can be integrated with both all air systems and also air-water/refrigerant systems. Savings should be maximised through the use of Variable Speed Drives on fans.

A holistic design approach should be followed while designing building interiors to enable good indoor air quality. Interior designers and contractors should be made aware of the importance of using low emission products while constructing the interiors. Architects and interior designers should also coordinate with the Heating, Ventilation and Air Conditioning (HVAC) designers to design the most suitable HVAC system for the project.

The supply and return air ducts should be placed appropriately to ensure adequate ventilation in all the working space and to avoid short circuit of ventilation system and stagnant pockets. Care should be taken while designing underfloor air distribution systems to avoid placing floor air inlets in the circulation areas. Minute aspects such as unwanted drafts, radiant asymmetry etc. should also be taken care of while designing seating in work and meeting places. Although most of the technical decisions pertaining to HVAC system should not fall in the domain of work of interior designers, it is highly recommended that the interior designers should communicate the design with the HVAC designers at the earliest. This helps in ensuring most of the above mentioned aspects as well as gives the HVAC designers a reliable brief to work on.

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