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Refrigerator/Freezer Energy Efficiency Improvement in the APEC Region: Review of Experience and Best Practices

APEC Energy Working Group

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1. Introduction

Among all home appliances, refrigerators consume the most energy in the world accounting for around 30% of the total energy consumption. The annual production of refrigerators in 2015 was about 150 million units with a rapid growth trend, and around 1.5 billion units are in use worldwide (CLASP website). The energy consumed by refrigerators is rapidly growing, especially in developing APEC economies, which has a great impact on APEC energy intensity reduction goals if no active assistance with efficient promotion of refrigerators is provided.

Many APEC economies including the USA; Japan; China; Korea; Australia; New Zealand; and Chinese Taipei have succeeded in boosting the overall energy efficiency (EE) of refrigerators through technology developments and EE management systems, as well as appropriate subsidies. However, some developing economies such as the ASEAN economies and Central and South America regions are still pending trials. They not only need to build integral EE management systems, but also need to strengthen their refrigerator industry technical capacities to achieve overall market efficiency improvements. The APEC region is expected to accelerate the refrigerator efficiency promotion through sharing successful experience regarding the enhancements of refrigerator efficiency technology and EE management systems to developing economies.

This project aims to build the capacity to implement high efficient refrigerator / freezer technologies and policies in developing APEC economies, meeting APEC energy intensity reduction goals, and the directives of the 2014 Ministerial Meeting to "enhance cooperation among member economies, get a deeper understanding of their R&D needs, build information platforms, develop Asia-Pacific intellectual networks, share R&D results, and strengthen practical project cooperation". In the past decade, the energy efficiency of refrigerators in many economies has been greatly enhanced, including aspects such as MEPS, mandatory benchmarking of EE labelling schemes, voluntary EE standards, and the harmonization of test standards. This project has conducted an investigation and an analysis of all of this information as the baseline for this project. Based on the project goals, this work has established a technical experts group to review and investigate energy efficiency promotion for refrigerators /freezers, and to manifest the causal effect of policy guidance on energy saving performance. At the same time, the market survey and benchmarking studies were also carried out for energy-saving key technology and product functional features to gain an understanding of the refrigerator market profile, which will assist with EE promotion for the

APEC developing economies in the near future. Through the holding of workshops to disseminate study results and collect available opinions, this project initiated the experience-sharing platform for domestic refrigerators / freezers designs for energy issues to improve the information exchange mechanism and technical training among the APEC region members.

2. Project Objectives and Implementation

The purpose of this project is to pave a way for accelerating the establishment of a cooperative mechanism for high efficient refrigerator/freezer designs and the corresponding policy implementation. The objectives of the project are listed below:

Objective 1: To evaluate energy efficiency management systems and policies for refrigerators and provide policy suggestions for the economies in the APEC region

Objective 2: To evaluate the available energy saving technology related to refrigerators under EE regulations

Objective 3: To select best practical cases for studying the method for improving the market share for high efficiency refrigerators

Objective 4: To establish a refrigerator energy saving knowledge to share platform and to integrate a refrigerator network of EGEE&C to provide energy saving designs information

Objective 5: To spread project experiences, sharing the best practices, and collect comments within the APEC region.

The progress towards meeting the objectives of this project will be evaluated through the following indicators:

(1) This project will distribute a questionnaire surveying the energy efficiency management and technology development issues of refrigerators to the members of developing economies seeking their participation in this project. The technical expert group meeting will help to identify the actual needs of developing economies and provide the latest energy-saving knowledge to them. The policy makers in the developing economies are expected to enhance their domestic EE management programs, accordingly.

(2) By holding workshops, the economies with successful experiences with refrigerator EE promotion can share their histories and the benefits of policy implementation processes by presenting their case studies results. This will enhance the learning capacity for EE management and energy conservation application in the APEC region.

(3) Case studies for policy implementation for EE promotion for refrigerators include energy-saving technology development or introduction, the relevance of energy-saving technologies and EE benchmarks, the designs of EE management programs, market surveillance methods, laboratory test procedures and product verification, efficiency improvement, and stakeholder's meeting processes and subsidies. The research results will be helpful to the development of future energy efficiency management and benchmarking in developing economies.

(4) Refrigerators are so-called white appliances, to which women often pay close attention. This study promotes women's participation in the study of energy-saving & carbon reduction issues. Therefore, refrigerators could be designed more in line with family needs.

(5) Following the evaluation results of the previous questionnaire survey, the project collects the information regarding the demands of energy saving technology and EE management affairs for refrigerator EE promotion, which will help with the organization of more training courses for developing economies.

At the first stage of this project's implementation through January 30, 2018, the team applied the outcomes from other APEC EWG projects relating to refrigerator topics, particularly the 'Harmonization of Energy Efficiency Test Methods of Refrigerators' (EWG 04 2014A, CSC, 2014) and made full use of and promoted the previous APEC project research results as relevant. Project EWG 04 2014A focused on EE testing harmonization for refrigerators with IEC 62552 standards (IEC, 2015), and supported the development of an effective management and inspection environment in the APEC region. The details of the survey works and the comparison among test methods and corresponding tested results was reviewed in the investigation report for this project (ITRI, 2018). As many economies in the APEC region are undergoing standard harmonization and transforming works following the announcement of IEC 62552 standards, the refrigerator test was an important issue when the project held the 1st and 2nd workshops. The outcomes for the issue discussion are described in this final report.

In order to understand EE management for refrigerators / freezers in the APEC region, the project team conducted a survey research with a detailed questionnaire, and the main objective of this questionnaire was to investigate the current situation of EE management systems and energy-saving technologies for refrigerators. The questionnaire was distributed to all of the APEC economies in October of 2017 and the initial findings were presented in the investigation report (ITRI, 2018). Continuous questionnaire surveying was conducted through technical expert group meetings respectively in November 2017, April 2018, and September 2018. Ten responses from Ten APEC economies were received, namely from Viet Nam; Indonesia; Thailand; Malaysia; New Zealand; Korea; Hong Kong, China; Japan; Singapore;

and Chinese Taipei. With regard to their geographical distributions, the vast majority of respondents were concentrated in the East Asia region and one was from New Zealand. The questionnaire results can be utilized as an instrument for future domestic refrigerators/freezers design and EE regulation in the APEC region, and have been updated in this final report.

To gather international experts in EE refrigerators / freezers to discuss the latest technology developments for refrigerators / freezers in energy saving, the working group of Chinese Taipei hosted a self-funding refrigerator seminar titled 'Energy Saving Technology Seminar for Refrigerator/Freezer Energy Efficiency Improvement in APEC Region' on 16 November, 2017 at the Howard Plaza Hotel, Taipei City. The topics of the seminar included:

- Topic 1: Integration of Appliances for Smart Homes, by ITRI (Dr Morris Pei-Fang Liang)
- Topic 2: Standard Harmonization for Performance Tests for Refrigerators / Freezers, by Vkan Certification & Testing Co, Ltd (CVC), China (Mr Andy Li Tie)
- Topic 3: Next Possible Refrigerant for Environmental Consideration, by Honeywell International (China) Co Ltd (Dr Yongming Niu)
- Topic 4: State-of-the-Art Refrigerator Compressor Designs, by Cubigel Compressors, Huayi Bacelona, Electrolux Group (Mr Alejandro Vázquez Escámez)
- Topic 5: System Design for Energy Efficiency Improvement of Household Refrigerators / Freezers , by ITRI (Mr Tony Wen-Ruey Chang)

The project also invited experts from developing economies in the APEC region to participate the seminar and the 1st technical expert group meeting on 17 November, 2017 to discuss the outcomes of the previous survey study and the case studies in this project, including the economics of Indonesia; Malaysia; Thailand; and Viet Nam. Forty attendees from domestic manufactures and laboratories participated in this seminar. There was no gender restriction for the participants in this event. About 15% of the attendees were female, and 11% of all speakers and APEC participants were women. This event provided an information sharing platform for developing economies and domestic manufacturers in Chinese Taipei. The project summarized the outcomes and suggestions of the seminar and the technical expert group meeting shown in the investigation report of this project (ITRI, 2018).

In order to promote and evaluate the available energy saving technology, energy efficiency management system, and policy for refrigerators for the APEC economies under EE regulations, the working group hosted the 1st workshop on 9 April, 2018 in Washington, DC, USA as shown in Annex I of the agenda. The topics of Workshop I included:

- Topic 1: Introduction to the EWG 07 2017A Project and its Implementation Status, by Ms Nicole Yun-Tzu Guo, Industrial Technology and Research Institute (ITRI), Chinese Taipei
- Topic 2: Experience sharing of USA on EE promotion of refrigerator /freezer under energy efficiency regulation, by Dr Stephanie Johnson, Department of Energy, USA
- Topic 3: Experience sharing of Chinese Taipei on EE promotion of refrigerator /freezer under energy efficiency regulation, by Mr Tony Wen-Ruey Chang, Industrial Technology and Research Institute (ITRI), Chinese Taipei
- Topic 4: Experience sharing of Japan on EE promotion of refrigerator/freezer under energy efficiency regulation, by Mr Hiroki Yoshida, Ministry of Economy, Trade and Industry, Japan
- Topic 5: Experience sharing of New Zealand on EE promotion of refrigerator/freezer under energy efficiency regulation, by Mr Eddie Thompson, Energy Efficiency & Conservation Authority, New Zealand
- Topic 6: Conclusion for Case Studies of Refrigerators/Freezers Design and Implementation under Energy Efficiency Regulation, by PO
- Topic 7: the 2nd Technical Expert Group Meeting

Five expert speakers and 18 attendees from 10 economies participated in this workshop to facilitate the sharing of history and the benefits of policy implementation processes among the APEC economies with successful experiences with refrigerator EE promotion, including the USA; Japan; New Zealand; and Chinese Taipei. Five active participants of travel-eligible APEC member economies from Indonesia; Malaysia; Mexico; Thailand; and Viet Nam, also attended this event. There was no gender restriction for participants in this event. Attendance was about 11% female, and 20% of all of the speakers and APEC participants were women. This event provided a refrigerator energy saving knowledge sharing platform and refrigerator network integration of EGEE&C to provide energy saving design information. Through the gathering of successful experiences with the enhancement of refrigerator efficiency technology and EE management systems, the up-to-date information of energy efficiency regulations and management systems in each respective economy was collected and summarized by the end of April, 2018. The project team also completed the Investigation Report for Case Studies of Refrigerators / Freezers Design and Implementation under Energy Efficiency Regulations (ITRI, 2018) by 30 April, 2018.

In order to conduct a study of successful EE management programs and to identify the best practices for approaching energy efficiency improvement methodologies and outcomes, this project invited expert speakers from refrigerator manufacturers and institutes to share practical case experiences in energy efficiency improvements in domestic refrigerators under EE regulations in the 2nd workshop held on 11 September, 2018 in Chiang Mai, Thailand during the APEC EGEE&C 52 meeting. The topics of the Workshop II included:

Topic 1: Introduction to the EWG 07 2017A Project and its Implementation Status & the Recent Developments in Energy Efficiency Technology and Management for Refrigerators / Freezers in the APEC Region, by Mr Tony Wen-Ruey Chang, Industrial Technology and Research Institute (ITRI), Chinese Taipei

Topic 2: Experience sharing of Thailand on Refrigerators / Freezers Energy Efficiency Improvements

- Energy Efficiency for Refrigerator(MEPS and HEPS) Under Energy Conservation Act in Thailand, by Dr Supachai Sampao, Department of Alternative Energy Development and Efficiency, Ministry of Energy, Thailand
- Experience sharing on refrigerator energy efficiency promotion, by Mr Pawatt Suwannakut, Electrical and Electronics Institute, Thailand

Topic 3: Experience sharing of Chinese Taipei on Refrigerator/Freezer Energy Efficiency Improvement, by Mr Tony Wen-Ruey Chang, Industrial Technology and Research Institute (ITRI), Chinese Taipei.

- Go Smart Life ECO by TECO, by Mr Chi-Tseng Peng, Household Appliances Group, TECO Electric & Machinery Co, Ltd, Chinese Taipei
- Panasonic Green Design, by Mr Heng-Chun Lee, Refrigerator R&D Department AP Development Center, Appliances Domain Business, Panasonic Co Ltd, Chinese Taipei

Topic 4: Experience sharing of China on Refrigerator/Freezer Energy Efficiency Improvement, by Dr LI, Pengcheng, China National Institute of Standarization, China

Topic 5: Experience sharing of Viet Nam on Refrigerator/Freezer Energy Efficiency Improvement, by Ms Doan Thi Thanh Van, Viet Nam Standards and Quality Institute (VSQI), Viet Nam

Topic 6: Experience sharing of Malaysia on Refrigerator/Freezer Energy Efficiency Improvement, by Mr ChokSer Gan, Cooling Innovation Sdn Bhd Malaysian Air-Conditioning & Refrigeration Association (MACRA), Malaysia

Topic 7: Panel Discussion and Conclusion for Review of Experience and Best Practices, by Project Manager and Technical Working Group Member

Topic 8: Technical Expert Group Meeting

In total, eight expert speakers and 45 attendees from 12 economies participated in this workshop. The project team also assisted in the nomination and travel reimbursement for four active participants from travel eligible economies. There was no gender restriction on the participants of this event. Female experts were about 11.1% of the attendees, and 8.3% of all of the speakers and APEC participants were women.

The case studies for EE promotion of refrigerators included the energy-saving technology development, energy efficiency management, and other incentives to explore the mechanism for improving the efficiency of marketing refrigerators. Based on the results of the previous investigation study, the project team also provided consultation and disseminated the implementation of EE improvement for refrigerators / freezers following the successful studied methodologies and outcomes. The design and manufacturing expenditures for the improvements were self-funded by the manufacturers. All of these studied efforts and the resultant energy conservation knowledge were presented in the 2nd workshop and compiled in the final report. The workshop significantly expanded the collective knowledge of EE management and energy conservation application in the APEC region.

3. Study Approach

3.1 Questionnaire Survey and Outcomes

3.1.1 Questionnaire Background

The questionnaire survey is one of the outcomes of the EWG 07 2017A project, “Refrigerator/Freezer Energy Efficiency Improvement in APEC Region: Review of Experience and Best Practices”. The main objective of this questionnaire was to investigate the current situation of refrigerator energy efficiency (EE) management systems and energy-saving technologies in the APEC region. The questionnaire was distributed to all the APEC economies in Mid-October 2017 and initial findings were subsequently presented at the second day of the Energy Saving Technology Seminar in Chinese Taipei held on 17 November, 2017. Continuous questionnaire surveying was conducted through technical expert group meetings respectively in November 2017, April 2018, and September 2018. The questionnaire results can be utilized as an instrument for future domestic refrigerators / freezers design and EE regulations in the APEC region.

A. Design of the Questionnaire

The questionnaire contained 19 questions in total and was divided into 4 parts. Each part of the questionnaire consisted of both open-ended and closed-ended questions, the answers to which provided quantifiable results and valuable input from each respondent.

The first part included mostly open-ended questions allowing respondents to provide precise information regarding refrigeration markets in their economies. The second part requested respondents to indicate the implementation of EE management policies for refrigerators in their economies. The objective here was to understand what policies were implemented in each economy to govern refrigerator EE. The third part examined EE test methods for refrigerators in the respondent economies. The answers in this part can help us to understand whether EE test methods for refrigerators in each economy are aligned with the international standards, i.e. IEC standards. The last part contained mostly close-ended questions, which in reply respondents identified currently-used technologies for refrigerator EE and the technology needed to improve the domestic refrigerator EE in their respective economies.

B. Questionnaire Responses

Ten responses from Ten APEC economies were received, namely from Viet Nam; Indonesia; Thailand; Malaysia; New Zealand; Korea; Hong Kong, China; Japan; Singapore and Chinese Taipei. With regard to their geographical distribution, the vast majority of respondents were concentrated in East Asia region and one was from New Zealand.

3.1.2 Analysis of the questionnaire

Part 1- Refrigerator market

Three types of refrigerators are discussed in part 1 of the questionnaire, namely refrigerator only, refrigerator & freezer, and freezer only.

Q1: Annual sales of refrigerators/freezers in your economy?

Q2: Annual sales of ***domestic*** *refrigerators/freezers in your economy?*

The answers to Q1 and Q2 were analyzed together and interpreted to obtain a percentage of annual sales of domestic (household) refrigerators / freezers in each economy. Key findings are presented below:

(1) Refrigerator only

- Domestic refrigerators accounted for 100% in New Zealand and Japan.
- Indonesia had up to 90% of domestic refrigerators in the Indonesian market.
- In Chinese Taipei, domestic refrigerators accounted for 75% in their market.
- The other six economies left this question blank.

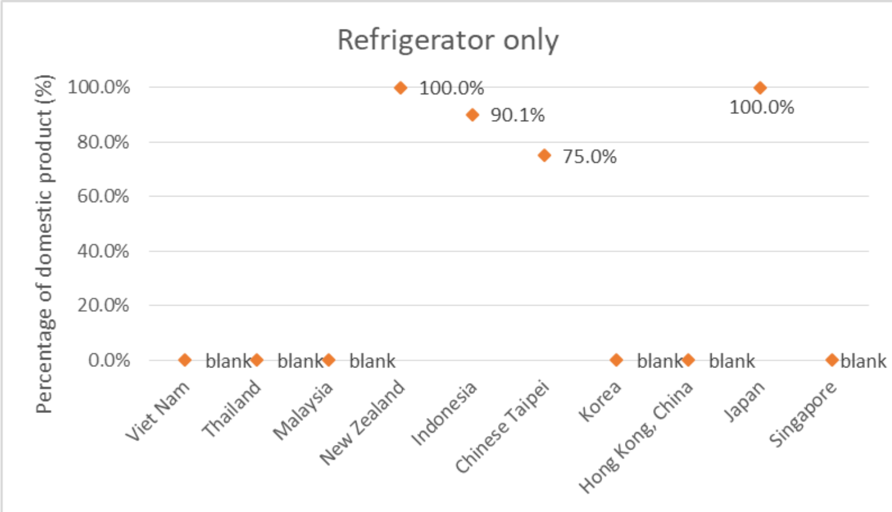

Figure 1 Percentage of annual sales of domestic refrigerators

(2) Refrigerator & Freezer

- Domestic Refrigerator & Freezers accounted for 40% in Viet Nam.
- 73% of Indonesian Refrigerators & Freezers were domestically manufactured.
- 65% of Refrigerators & Freezers in Chinese Taipei were manufactured domestically.
- All of the Refrigerators & Freezers in Japan were manufactured locally.
- The other six economies left this question blank.

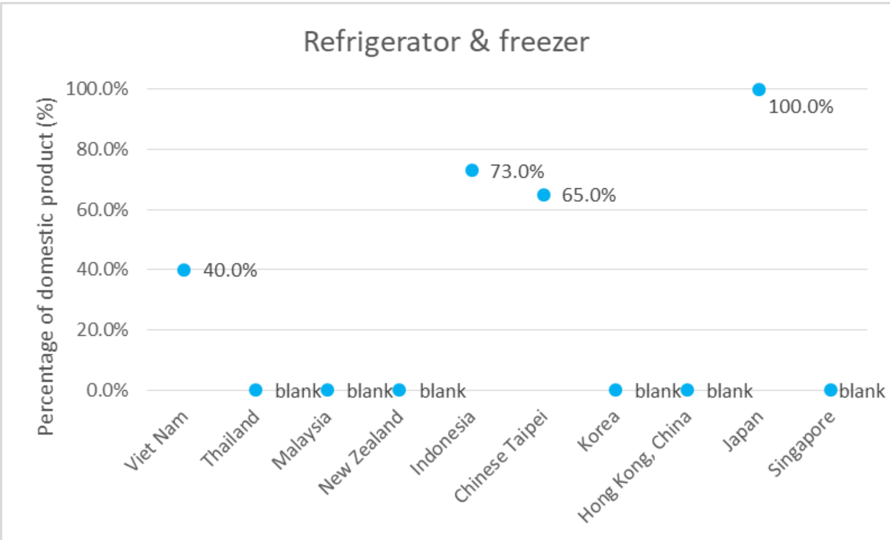

Figure 2 Percentage of annual sales of domestic refrigerators & freezers.

(3) Freezer only

- In Indonesia, 58.1% of all freezers were domestically manufactured.
- Domestic freezers accounted for 12.5% in the Chinese Taipei refrigeration market.
- All freezers in Japan were manufactured domestically.
- The other seven economies left this question blank.

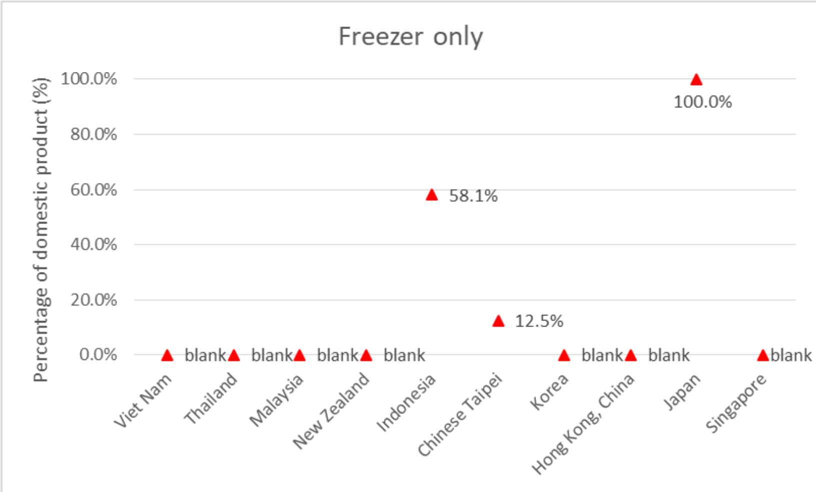

Figure 3 Percentage of annual sales of domestic freezers

Q3: What is the adjusted volume that represents the most commonly-used refrigerator / freezer in your economy?

- According to Figure 4, Refrigerator & Freezer was the most common refrigerator type in all of the respondent economies.
- The largest Refrigerator & Freezer was reported by Korea while the smallest one was found in Indonesia.
- New Zealand; Indonesia; and Chinese Taipei indicated the adjusted volume for all three types of refrigerators. Malaysia and Korea reported the adjusted volume of refrigerator only and Refrigerator & Freezer. Viet Nam and Japan only showed the adjusted volume for Refrigerator & Freezer in their economies.
- A 111-liter refrigerator was the representation in New Zealand's market. A 500-liter Refrigerator & Freezer was the most commonly-used type in New Zealand. A 530-liter freezer was the most commonly-used in New Zealand's households.

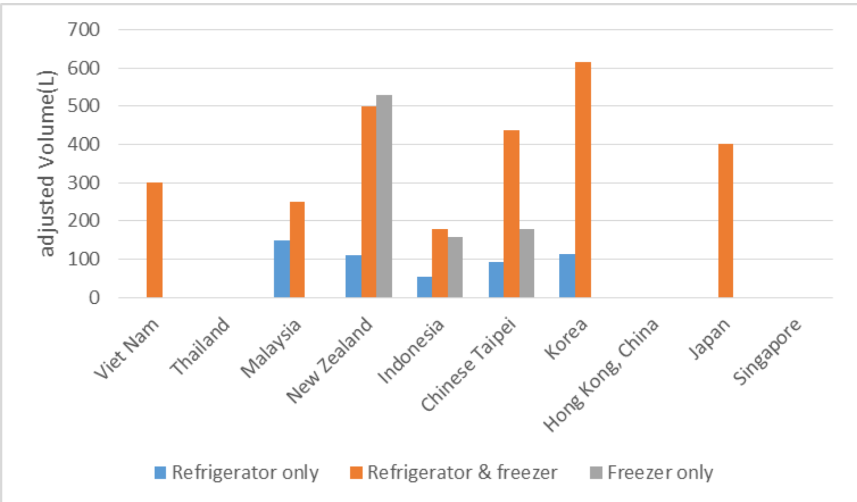

Figure 4 Adjusted volume that represents the most commonly-used refrigerator / freezer

Q3-1: Annual energy consumption of the most commonly-used refrigerator/freezer.

(1) Refrigerator only

- Half of the responding economies answered this question.
- The smallest refrigerator was used in Indonesia, which was also cited with the highest annual energy consumption among the five responding economies.

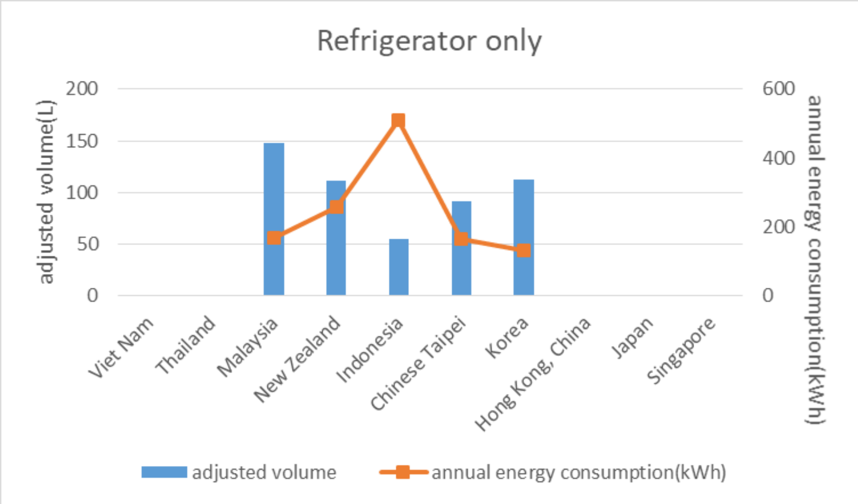

Figure 5 Annual energy consumption of the most commonly-used refrigerator

(2) Refrigerator & Freezer

- Seven economies answered this question.
- The largest adjusted volume of Refrigerator & Freezer was found in Korea, which consumed relatively low energy.
- Indonesia had the highest annual energy consumption for Refrigerator & Freezer but the lowest in adjusted volume.

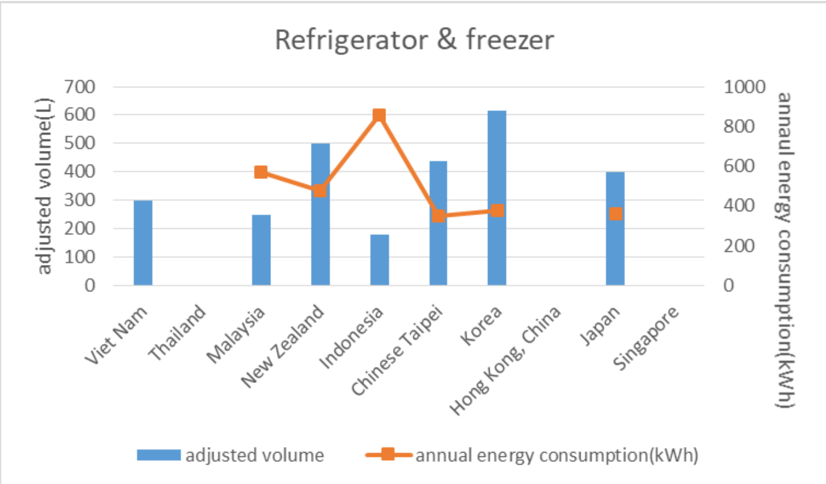

Figure 6 Annual energy consumption of the most commonly-used refrigerator & freezer

(3) Freezer only

- New Zealand; Indonesia; Chinese Taipei; and Japan answered this question. However, Japan only indicated the annual energy consumption of freezers without indicating the adjusted volume of their freezers. Chinese Taipei only indicated the adjusted volume of their most commonly-used freezer.

- A 530-liter freezer was the most commonly-used freezer in New Zealand households. The annual energy consumption of that model was 402.6 kWh.
- The adjusted volume of the most commonly-used freezer in Indonesia was 158 liters. The annual energy consumption was 1025.65 kWh.

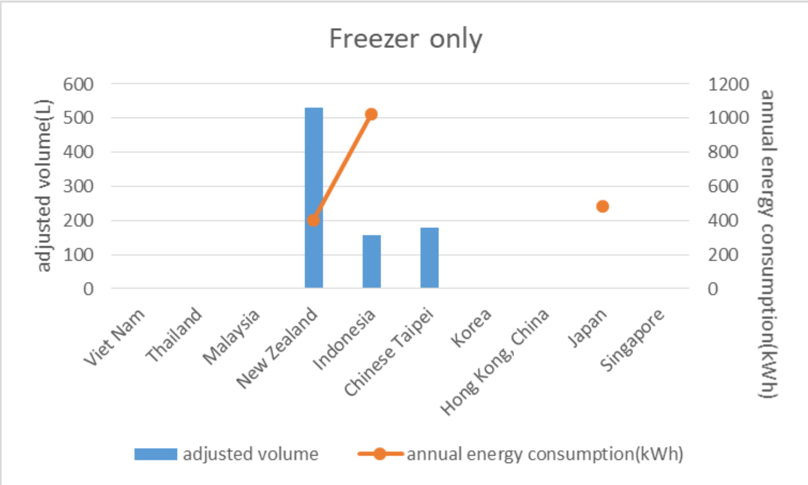

Figure 7 Annual energy consumption of the most commonly-used freezer

Q4: What is the penetration rate of refrigerators / freezers in your economy? Answer should be from 0 to 100%. (A penetration rate of 80% means that 80% of households have at least one refrigerator / freezer and 20% of households do not have any refrigerator/freezer.)

- Refrigerator & Freezer had the highest penetration rate in most economies.
- According to Figure 8, Refrigerator & Freezer had a more than 90% penetration rate in New Zealand; Chinese Taipei; Korea; Japan; and Singapore.
- The penetration rate for freezers in New Zealand was the highest, at 50%. On the other hand, Chinese Taipei has the lowest penetration rate for freezers, at only 3%.

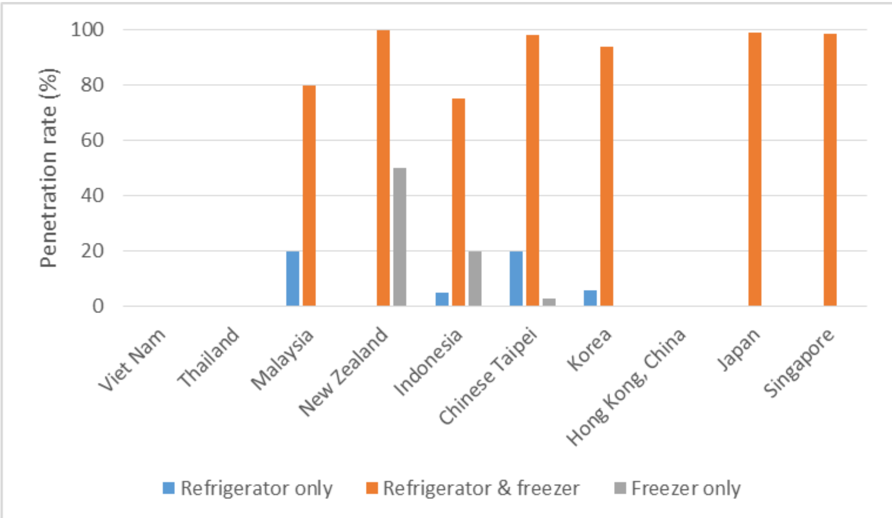

Figure 8 Penetration rate for refrigerators / freezers

Q5: How many refrigerators / freezers are there in an average family home?

- According to Table 1, most economies had 1 to 2 refrigerators in an average family home.

Table 1 Numbers of refrigerators / freezers in an average family home

Economy	Refrigerator only	Refrigerator & Freezer	Freezer only
Viet Nam	-	1-2	-
Thailand	-	-	-
Malaysia	1-2	1-2	NA
New Zealand	1-2	1-2	1-2
Indonesia	1-2	1-2	1-2
Chinese Taipei	<1	1-2	<1
Korea	1-2	1-2	NA
Hong Kong, China	-	-	-
Japan	--	1-2	--
Singapore	--	--	--

Part II- EE management policies

Q6: Does your economy implement EE policies for refrigerators/freezers?

- All of the respondent economies have implemented EE policies for refrigerators/freezers.

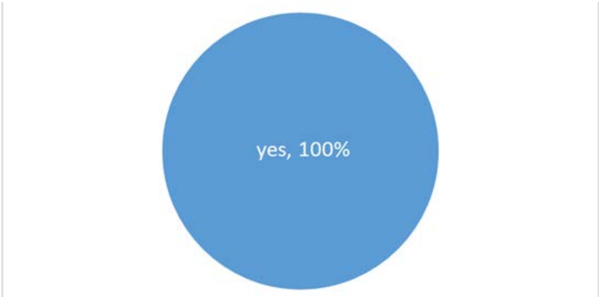

Figure 9 Does your economy implement EE policies for refrigerators/freezers?

Q7: Does your economy implement voluntary labeling (certification) for refrigerators/freezers?

- Half of responding economies had a voluntary labeling program for refrigerators / freezers.
- Four out of ten economies had no voluntary labeling program for refrigerators / freezers.

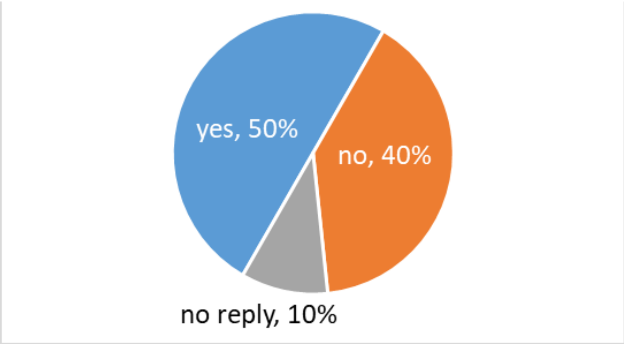

Figure 10 Does your economy implement voluntary labeling (certification) for refrigerators/freezers?

Q7-1: If yes, when was it implemented? How often does your economy revise the certification standards?

- Among all of the responding economies, Malaysia was the first economy to implement a voluntary labeling program for refrigerators/freezers and the certification standard was revised every 3 to 5 years.

Table 2 Voluntary labeling for refrigerators / freezers

Economy	Q7. Does your economy implement voluntary labeling (certification) for refrigerators / freezers?	Q7-1. If yes, when was it implemented?	Q7-2. How often does your economy revise the certification standards?
Viet Nam	No		
Malaysia	Yes	1993	3~5 years
Indonesia	No		
Thailand	No		
New Zealand	Yes	2003	Depend on IEC standard
Chinese Taipei	Yes	2001	7 years
Korea	-		
Hong Kong, China	Yes	1995	2~3 years
Japan	Yes	2000	--
Singapore	No	--	--

Q8: Does your economy implement Minimum Energy Performance Standards (MEPS) for refrigerators / freezers?

- Eight responding economies had MEPS for refrigerators / freezers.
- Hong Kong, China was the only respondent without MEPS for refrigerators / freezers.
- Japan implemented a different type of program for refrigerators/freezers, i.e. Top

Runner program, a maximum standard value system.

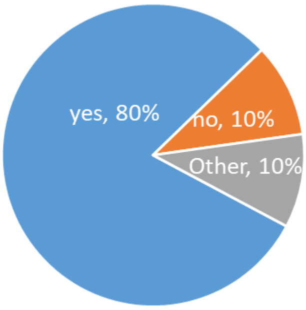

Figure 11 Does your economy implement Minimum Energy Performance Standards (MEPS) for refrigerators / freezers?

Q8-1: If yes, when was it implemented? How often does your economy revise the standards?

- Among all of the responding economies, Korea was the first to implement MEPS for refrigerators / freezers. MEPS is revised every 5 years.

Table 3 MEPS for refrigerators / freezers

Economy	Q8. Does your economy implement MEPS for refrigerators/freezers?	Q8-1. If yes, when was it implemented?	Q8-2. How often does your economy revise the standards?
Viet Nam	Yes		
Malaysia	Yes	2004	10
Indonesia	Yes	2014	5
Thailand	Yes	2002	5
New Zealand	Yes	2017	Depends on IEC standard
Chinese Taipei	Yes	2010	8
Korea	Yes	1992	5
Hong Kong, China	No		
Japan	Other program		
Singapore	Yes	2008	Not specified. Revisions in 2014 and 2017

Q9: Does your economy implement a mandatory labeling programs for refrigerators/freezers?

- All the responding economies have implemented labeling program for refrigerators/freezers.

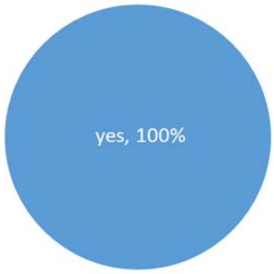

Figure 12 Does your economy implement a mandatory labeling program for refrigerators/freezers?

Q9-1: If yes, when was it implemented? How often does your economy revise the standards?

- As with Q8, Korea was the first to implement labeling for refrigerators / freezers. They revise the standard every five years.

Table 4 Mandatory labeling program for refrigerators/freezers

Economy	Q9-1. If yes, when was it implemented?	Q9-2. How often does your economy revise the standards?
Viet Nam	--	--
Malaysia	2004	10
Indonesia	2014	5
Thailand	2002	5
New Zealand	2017	Depend on IEC standard
Chinese Taipei	2010	8
Korea	1992	5
Hong Kong, China	2009	1
Japan	1998	--
Singapore	2008	Not specified. Revisions in 2014 and 2017

Q10: Does your economy maintain a registry of approved refrigerators / freezers?

- All of the responding economies except Japan maintain a registry of approved refrigerators/freezers.

Q11: Does your economy have a market surveillance program of efficient refrigerators / freezers? If yes, how many refrigerators/freezers are tested annually in the market surveillance program?

- All of the responding economies except Japan have a market surveillance program for refrigerators / freezers.

Table 5 Other policy information

Economy	Q10.Does your economy maintain a registry of approved refrigerators/freezers?	Q11-1.Does your economy have a market surveillance program of efficient refrigerators/freezers?	Q11-2.If yes, how many refrigerators/freezers are tested annually in the market surveillance program?
Viet Nam	Yes	Yes	5
Malaysia	Yes	Yes	when necessary
Indonesia	Yes	Yes	depends on the government budget
Thailand	Yes	Yes	30
New Zealand	Yes	Yes	tested through a joint program with Australia
Chinese Taipei	Yes	Yes	40~60
Korea	Yes	Yes	10~20
Hong Kong, China	Yes	Yes	5% of models approved annually
Japan	No	No	
Singapore	Yes	Yes	Not annually, but in 2014, 20 refrigerators / freezers were tested.

Part III- Test methods

Q12: Are you using IEC 62552:2015 for refrigerators/freezers EE testing?

- Viet Nam and Japan are following IEC 62552:2015 for refrigerator/freezer EE testing.

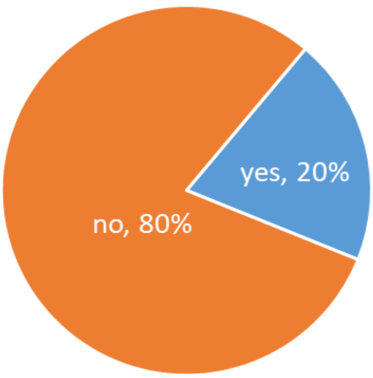

Figure 13 Are you using IEC 62552:2015 for refrigerators/freezers EE testing?

Q12-1: If not, what standard does your economy use?

Q12-2: Are you planning to adopt IEC 62552:2015?

Eight economies listed in

- Table 6 are using their own test methods for refrigerator/freezer EE testing. 6 of them plan to adopt IEC 62552:2015 in the future.

Table 6 Current test methods and plans to adopt IEC 62552:2015

Economy	Current test method	Plan to adopt IEC 62552:2015?
Thailand	TIS 2186-2547(2004)	Yes
Malaysia	IEC 62552:2011	Yes
New Zealand	AS/NZS 4474.1:2007	Yes
Indonesia	ISO 15502:2008	Yes
Chinese Taipei	CNS 2062	Yes
Korea	KS C IEC 62552:2014	Yes
Hong Kong, China	IEC 62552:2007	-
Singapore	IEC 62552:2007	--

Q13: Did your economy participate in the harmonization of energy efficiency test methods for refrigerators / freezers toward the IEC 62552:2015?

- Viet Nam and Japan participated in the harmonization of energy efficiency test methods for refrigerators / freezers toward the IEC 62552:2015.
- Malaysia participated in a similar refrigerator harmonization project, the Electrical and Electronic Equipment MRA (EEMRA).
- Thailand; New Zealand; Indonesia; Chinese Taipei; Korea; and Hong Kong, China had no experience participating in the harmonization of energy efficiency test methods for refrigerators / freezers toward the IEC 62552:2015.
- Singapore left this question blank.

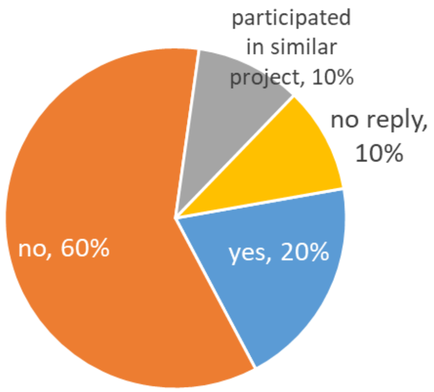

Figure 14 Did your economy participate in the harmonization of energy efficiency test methods for refrigerators/freezers toward the IEC 62552:2015?

Q13-1: Does your economy need assistance with standard harmonization in the *future?*

Q13-2: Please name any assistance needed.

- Half of the economies indicated that they need assistance with standard harmonization in the future, with three clearly identifying what assistance they need.
- Viet Nam; Malaysia; Indonesia; and Chinese Taipei pointed out that they need assistance with standard harmonization in the future. Three out of four economies clearly stated what type of assistance they need.

Table 7 Indication of assistance needed with respect to standard harmonization in the future

Economy	Q13-1.Does your economy need assistance with standard harmonization in the future?	Q13-2.Please identify any assistance needed
Viet Nam	Yes	Update new standards Competence test Round robin test Market surveillance if possible
Thailand	No	--
Malaysia	Yes	Facilities and training
New Zealand	No	--
Indonesia	Yes	--
Chinese Taipei	Yes	Testing procedures & calculation method
Korea	No	--
Hong Kong, China	No	--
Japan	No	--
Singapore	--	--

Part IV- Technology needed for refrigerator/freezer EE

Q14: What is the percentage of domestic refrigerators / freezers using DC compressors in your economy?

- Viet Nam; Thailand; Malaysia; and Indonesia stated that less than 20% of their domestic refrigerators / freezers use DC compressors, representing 40% of all responding economies.
- Chinese Taipei; Korea; and Hong Kong, China pointed out that more than 50% of their domestic refrigerators / freezers used DC compressors, making up 30% of all respondents.
- New Zealand; Japan; and Singapore left this question blank.

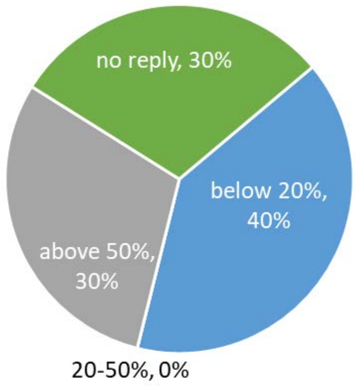

Figure 15 Percentage of domestic refrigerators/freezers using DC compressors

Q15: What is the most commonly-used refrigerator / freezer type?

- Viet Nam; Malaysia; Japan; and Chinese Taipei use fan-circulation type refrigerators / freezers.
- Thailand; Indonesia; and Hong Kong, China use direct cooled type refrigerators / freezers.
- New Zealand; Korea; and Singapore left this question blank.

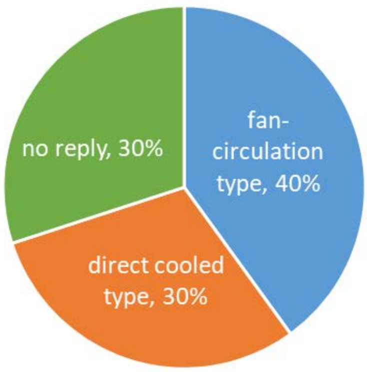

Figure 16 Most commonly-used refrigerator/freezer type

Q16: Is it common to use Vacuum Insulation Panels (VIP) for thermal insulation?

- VIP for thermal insulation was commonly-used in Viet Nam; Chinese Taipei; and Korea. VIP is not commonly used in refrigerators / freezers in Thailand; Malaysia; Indonesia; and Hong Kong, China.
- New Zealand; Japan; and Singapore left this question blank.

Figure 17 Is it common to use Vacuum Insulation Panels (VIP) for thermal insulation?

Q17: What kinds of refrigerants are most commonly-used for domestic refrigerators/freezers?

- Malaysia; Chinese Taipei; Korea; and Hong Kong, China use R-600a as refrigerants in their domestic refrigerators / freezers.
- Viet Nam; Thailand; and Indonesia use R-134a as refrigerants in their domestic refrigerators / freezers.
- New Zealand; Japan; and Singapore left this question blank.

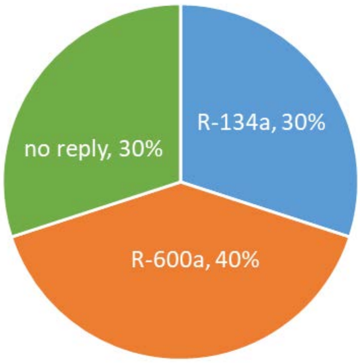

Figure 18 What kinds of refrigerants are most commonly-used for domestic refrigerators/freezers?

Q18: Refrigerator / freezer EE technologies used by domestic manufacturers:
Q19: What technologies do your domestic manufacturers need to implement or improve to achieve high refrigerator / freezer EE?

- Malaysia; Indonesia; Chinese Taipei; Korea and Hong Kong, China indicated what technologies are currently used by their domestic manufacturers and also identified the technologies they need to use to achieve higher efficiency refrigerators / freezers (see Table 8). Viet Nam; Thailand; New Zealand; Japan; and Singapore left Q18 and Q19 blank.
- For example, PU foaming insulation is a critical technology for Indonesia's refrigerators / freezers. However, standard harmonization for performance tests and compressor technology are needed in Indonesia's domestic refrigeration industry.

Table 8 Refrigerator/freezer EE technologies used in each economy and technology needs

Economy	Q18.Refrigerator / freezer EE technologies used by domestic manufacturers:	Q19.Technologies your domestic manufacturers need to implement or improve in order to achieve higher refrigerator / freezer EE?
Viet Nam	--	--
Thailand	--	--
Malaysia	• PU foaming insulation • System design	• Compressor technology • System design
New Zealand	--	--
Indonesia	PU foaming insulation	• Standard harmonization for performance tests • Compressor technology
Chinese Taipei	• DC compressor • PU foaming insulation • Vacuum Insulation Panels (VIP) • Heat exchange design • System design	• Smart appliance design • PU foaming insulation & VIP • Standard harmonization for performance tests
Korea	• DC compressor • Vacuum Insulation Panels (VIP) • System design	• Compressor technology
Hong Kong, China	• DC Compressor	• Compressor technology • Smart appliance design
Japan	--	--
Singapore	--	--

3.1.3 Results of the Questionnaire

According to the responses, it is discovered that questions regarding the refrigeration market and technology needs were not fully reported, whereas questions regarding EE management policies and test methods were given clearly responses. The replies to the questionnaires collected from ten respondents have confirmed that refrigerator & freezer is the most common refrigerator type used among all of the responding economies. Additionally, most economies have 1 to 2 refrigerators in an average family home.

In terms of energy efficiency management policies, all responding economies have confirmed implementing at least one type of EE policy for refrigerators / freezers. 80% of the responding economies reported the implementation of mandatory MEPS or similar programs. Furthermore, all respondents reported on the implementation of energy labeling programs. Compared to the high implementation rate of mandatory EE programs, voluntary EE programs that encourage high efficiency products were found in only five of the ten economies. In addition to the indication of EE policy implementation, the respondents were asked to specify when the programs were launched and the frequency in which standards are revised. Additionally, market surveillance and a registry of approved refrigerators / freezers were cited by all of the economies, except Japan.

With respect to current refrigerator / freezer test methods, Viet Nam and Japan are following IEC 62552:2015 for refrigerator / freezer EE testing. A vast majority of economies who were not following the latest version of international test method (IEC 62552:2015) indicated their intention to adopt IEC 62552:2015 in the future.

Six questions were asked regarding the technology used and needs for refrigerator / freezer EE. When questioned about DC compressors and VIP use, the most commonly-used refrigerator / freezer type, and currently-used refrigerants, seven out of ten economies (70%) were able to answer with specific replies. For example, Malaysia; Chinese Taipei; Korea; and Hong Kong, China indicated their use of R-600a as refrigerants in their domestic refrigerators / freezers while Viet Nam; Thailand; and Indonesia use R-134a. However, when asked about currently-used technologies and technology needed to achieve higher efficiency refrigerators / freezers, a lower response rate was found: only five out of ten respondents (50%) answered the questions. That is, Malaysia; Indonesia; Chinese Taipei; Korea; and Hong Kong, China reported the technologies that their domestic manufacturers are currently using and also identified the technologies they need to achieve higher refrigerators / freezers EE.

3.2 Technical Review and Outcomes of the Energy Saving Technology Seminar

The project successfully completed the survey and the collection of technical information regarding refrigerator EE promotion following literature reviews and the hosting of the self-funding refrigerator seminar, 'Energy Saving Technology Seminar for Refrigerator /Freezer Energy Efficiency Improvement in APEC Region' on 16 November, 2017 and the first technical expert group meeting on 17 November, 2017 at Taipei City. The outcomes of and suggestions from the seminar and the technical expert group meeting is described in detail in the investigation report (ITRI, 2018), this section will only refer to some brief reviews of EE technology.

3.2.1 Integration of Appliances for Smart Homes

The idea of smart homes began from the concept of home automation, and this goal is based on the availability of a smart home network for communication among devices. Although solutions for the home network have been discussed for years, and networking technologies through different media, such as power line, phone line, and the Ethernet have been tested and found and meet functional satisfaction, the applications of smart homes were not popular, as a gap remains between user habits and the services offered by the so-called smart appliances, including information and communication devices and network-enabled white goods. In the future, consumers will be able to remotely control temperature settings, the quick freezing function, view the refrigerator's self-diagnosis status, or start the system to filter heavier food. Furthermore, wireless blue-tooth speakers built into the above body can be connected to smart phones to play music.

Through the implementation of a smart grid and the popularization of smart home appliance users, it will be possible to integrate the power system and the real-time electricity usage information. This also can improve power systems and implement electricity dispatching into practice. Domestic appliances and ICT vendors have jointly spawned the "Smart Home Internet of Things communication standard - TaiSEIA 101" as an industry standard, laying an important foundation for building a smart grid and a smart power-related business service model for the future.

A smart meter system is the basic infrastructure of the Smart Grid. The standards for the communication protocol for the smart meter, IEC 62056 (IEC, 2017) and ANSI C12.22 (ANSI, 2012), are two main protocol standards. In order to ensure interoperability, DLMS/COSEM association provides a testing and certification rule for IEC 62056. However, the testing rule is only focused on the IEC62056 server, leaking a test plan for IEC 62056 clients.

As a field-trial project for smart energy management, functions such as automatic power saving tips and appliance remote diagnosis will be offered, and this service platform can be adopted for other value-added services, such as security, appliance remote control, and home care for aged people, to enhance life styles.

The dispatch flexibility of the power system can be highly increased through real-time response of the demand side, and the deployment of Advanced Metering Infrastructure (AMI) is the first step. Furthermore, Demand Response (DR) and Virtual Power Plant will be introduced after completion of the infrastructure. DR can deliver peak demand reduction and urgent power dispatching while a large amount of renewable energy is introduced to the smart grid (SG). SG can improve the quality of the power supply, system reliability, the adoption rate of renewable energy, and can achieve energy savings and peak demand reductions. Under the scope of SG, Demand Side Management (DSM) and power system operation are strongly integrated and interaction between utility and demand side can be made closer than ever.

3.2.2 Standard Harmonization

A. History

The first time refrigerator EE standards were released in China was 1989, standard no. GB 12021.2 – 89 (minimum energy consumption and test methods for household electrical refrigerators). In 1999, the GB 12021.2-89 standard was revised to promote energy efficiency improvements for the production of refrigerators. In 2007, this standard was revised twice. By 2012, combining stimulation policy issued on a economy level in which subsidies were issued for purchasing energy saving household appliances, the EE grade 1 products were increased to 90%, and products in grade 2 or in between grades 1 and 2 were covered 100% in the China market.

B. Why update?

According to a report on the market development status and future trends for refrigerators in China (2014-2018), the new standard will reach 5% of refrigerators in EE new grade 1 in the market, and 10%-20% of the products in EE new grade 2. From the Chinese Government's point of view, updating to the new standard will help consumers select higher energy efficiency products and support an incentive policy, such as Top Runner and Energy Star. For consumers, it is difficult to distinguish between high energy efficiency products and low energy efficiency products, according to current standards. Large differences existed between the energy consumption according to the standard and actual real life energy consumption, and also, it is difficult to understand the relationship between high price and high EEG for products. For manufacturers, it is important to advertise energy saving technology and new functions for improving energy efficiency. The elimination of international trade barriers and technology barriers can increase manufacturer benefits. In addition, MEPS for all high energy consumption industries and an international advanced level energy efficiency index of more than 80% production also eliminates more than 20% of outdated industries and high energy and water consumption industries (Tie, 2017).

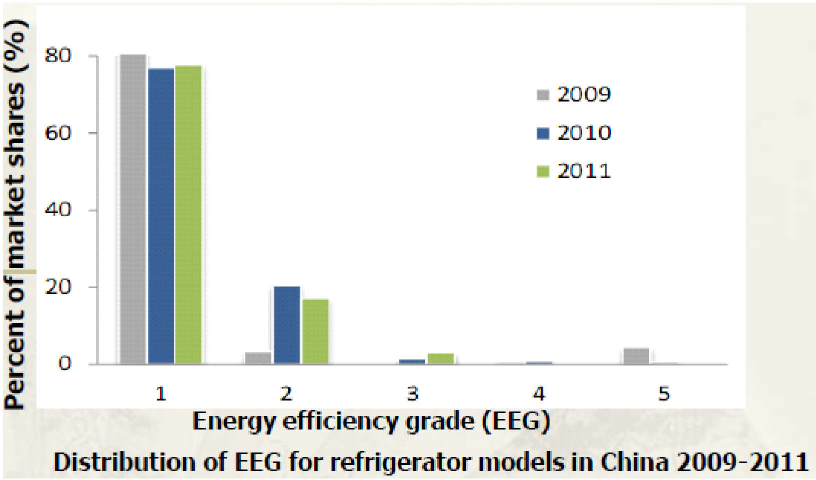

Figure 19 Refrigerator market share by energy efficiency grades in China

C. How to update

Due to demand from multiple stakeholders of EE standards in refrigerators, in 2013, the SAC (Administration of Standardization Commission of China) formulated a plan to revise the GB 12021.2-2008, which set a milestone for the official launching of the standard revision. From 2013 to 2015, preparation work for the standard revision was completed:

- 17 January, 2013, 1st workshop: It was concluded that the new IEC 62552 [3-5] would be the reference standard for China's revision of their standard, and energy consumption test methods in the new IEC 62552 standard have been agreed to implement round robin test among well qualified labs in China (CSC, 2014).
- 22 March, 2014, 2nd workshop: EE evaluation system and EE testing methods, EEI on the basis of laboratory test results in the 1st workshop, and more expansion laboratory test have been organized to collect a larger volume of test data (CSC, 2014).
- In September 2015, the newly revised "Minimum Energy Performance and EE Grade on household refrigerators" was issued, and it regulates that the new standard will come into effect on 1 October, 2016. Meanwhile, the new EE labelling will be implemented. The product scope of refrigerators, chest freezers, refrigerator freezers, and wine cellars are covered in the new China standard (GB, 2015).

D. What to update

Scope of products:

- Compressor-type household refrigerators
- Compressor-type household freezers
- Compressor-type household refrigerator-freezers (Load processing energy consumption test is needed)
- Compressor-type household frost-free refrigerator-freezers (Load processing energy consumption test is needed)
- Compressor-type wine coolers
- Compressor-type built-in refrigerating appliances

Table 9 Deviation between GB 12021.2-2015 and IEC 62552:2015

Standard	GB 12021.2-2015[9]	IEC 62552:2015[5]
Temperature	Day 16˚C: 192, Day 32˚C: 173	Day 16˚C: 170, Day 32˚C: 195
Relative humidity	50% ± 5%	No requirements
P_{ss1}	$(E_{end\text{-}C} - E_{end\text{-}A})/t_{ABC}$	No formula
Load processing efficiency test	Only for upright refrigerator-freezers	products for which the test was declared
Energy consumption of specified auxiliaries	Anti-condensation heater and tank-type	Anti-condensation heater

	automatic icemaker	
Thermostat setting of variable temperature compartment	Max. energy	Middle

E. How to meet the update

EE Policies such as the top runner program and energy star in China, government procurement, and others will be beneficial to the market and society. However, due to the changes in the standards, manufacturers and test labs must put more effort into meeting the requirements (Tie, 2017):

- Training for a thorough understanding of each part, item of testing, and algorithm in the new IEC 62552 must be organized. Especially with respect to load testing, uncertainty will arise following the regulated testing procedures. Hence, harmonized testing procedures must be drawn out. A much better option will be to refer to the Australian experience of RRT being organized to improve capacities at labs.
- One big change in the new IEC 62552 are the temperature conditions of both 16℃ and 32℃, as this has improved the adaptability of the standards in different geological regions. But, as manufactures have so many samples to be tested, and often in one test room some samples should be tested at 16℃ and others should be tested at 32℃, the test period for one test room will be prolonged. As such, it is necessary to build more test rooms or rebuild test rooms that can be divided into two parts and can be controlled at 16℃ and 32℃ simultaneously and separately for the two parts.
- Future products design must be improved to meet the new standard requirements, such as frequency conversion compressor application, heat-insulation property, and processes for foam materials, single-temperature-controllers being replaced by double-temperature-controllers, structures and raw materials for refrigerator doors, intelligent controlling system applications, and improvements to heat exchangers. Undoubtedly, application of those new technologies and new materials will result in higher costs for manufacturers and the same will be reflected in the product price. New ways to balance manufacturing costs, market prices, and policy leverage roles will require further research.

3.2.3 Refrigerant Trends

A. Overview

The 1st generation refrigerants are any gas that expands and compresses, as long as it works. Problems such as toxicity, flammability, and poor efficiency of these refrigerants are a concern. The 2nd generation uses refrigerants that are more durable and reliable. R12 and R22 are not flammable, and are non-explosive and non-toxic. However, the high Ozone depletion potential (ODP) has resulted in a depletion of the Ozone layer. The Montreal Protocol in 1987, which banned the use and production of high ODP refrigerants such as R11, as shown in Figure 20. Presently, refrigerants focus on protection of the ozone layer, which resulted in the 3rd generation of refrigerants. The substitute is R134a, which is now the most common refrigerant used in refrigerators and air conditioners. Owing to some regulations and limitations that have arisen in recent years, the tendency for refrigerants to have low global warming potential (GWP) has increased. Along with the EU's F-gas regulation, the usage of gases lower than 150 GWP value has become mandatory for vehicle air conditioning systems. The world is now trying to progress to the 4th generation of refrigerants, due to the high production of GWP in 3rd generation refrigerants. Low ODP and low GWP refrigerants are the main objectives, such as R1234yf; however this costs 10 times more than R134a because of the complex production process, as shown in Table 10. At the same time, in the selection of refrigerating fluids, refrigerants with thermodynamic properties such as high vaporizing temperatures and high gas densities are preferred for capacity improving and low energy consumption. Refrigerants decision-making criteria are shown in Table 11 (Goetzler, 2014).

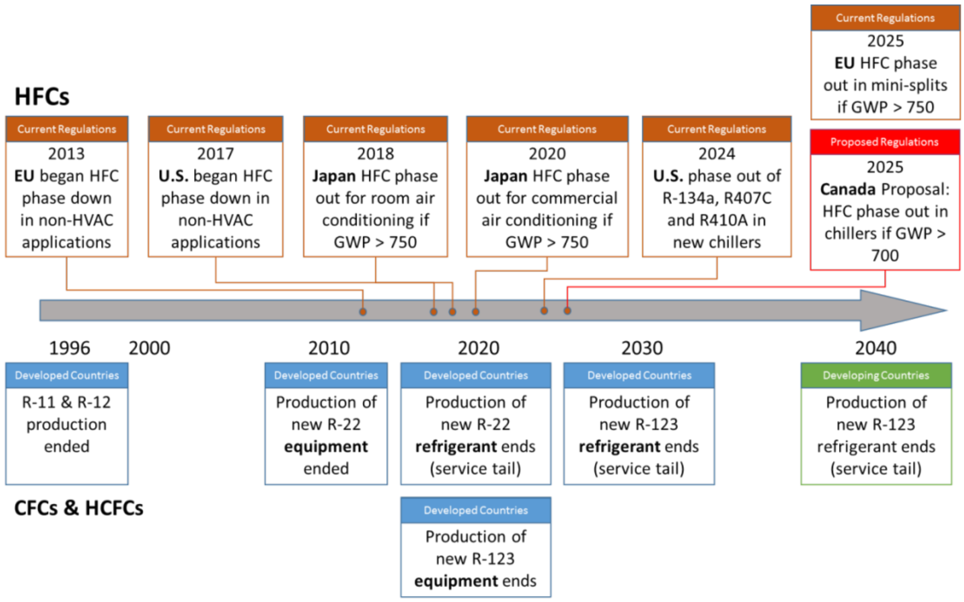

Figure 20 Refrigerants regulatory timeline

Table 10 Environmental effects of some common refrigerants

Compositional group	Refrigerants	Ozone depletion potential (ODP)	Global warming potential (GWP)
CFCs	R11	1	3800
	R12	1	8100
	R113	0.8	4800

Compositional group	Refrigerants	Ozone depletion potential (ODP)	Global warming potential (GWP)
HCFCs	R114	1	9000
	R115	0.6	9000
	R22	0.055	1500
	R123	0.02	90
	R124	0.022	470
	R141b	0.11	630
	R142b	0.065	2000
HFCs	R23	0	11700
	R32	0	650
	R125	0	2800
	R134a	0	1300
	R143a	0	3800
	R152a	0	140
	R410a	0	1924
HFOs	R1234yf	0	4
	R1234ze	0	7
Natural Refrigerants	R290	0	3
	R600a	0	3
	R717	0	0
	R718	0	0
	R744	0	1

Table 11 Decision-Making Criteria for refrigerants

Consideration	Criteria
Environmental	1. Low global warming potential 2. Zero Ozone depletion 3. Good life cycle climate performance in all climates. 4. Recycling and reclamation
Safety	1. Safe in use, storage and transport 2. Comprehensive toxicology testing 3. Acceptable flammability
Performance	1. High energy efficiency over complete operating range 2. Long-term durability
Cost-To-Serve	1. Low capital cost 2. Low operating cost 3. Low system maintenance

B. Alternative refrigerants

(a) R1234yf

R1234yf is an HFO that can be potentially used as a replacement for R134a. It has similar properties to R134a but with a much lower GWP. Experiments were conducted for a typical R134a system compared to R1234yf systems. The cooling capacity and COP of the R1234yf system are considerably lower than the baseline R134a system. However, their values can be improved significantly with some simple hardware modifications:

(1) Tuning the thermal expansion valve (TXV) setting

(2) Optimizing the variable displacement compressor control valve.

(To compensate for the different pressure drop and higher velocities, a longer suction line is needed). One of the problems encountered is the flammability of R1234yf. It does burn, but, it takes a significant amount of heat to ignite it and it burns slowly (Requirements for the safe handling and storage of R1234yf are still needed). Another problem is the cost. It is expected to be about ten times more expensive than R134a, due to the more complex production process and scarcity (not many companies are producing R1234yf because of the uncertainty regarding its future adoption).

Table 12 Comparison of R12, R134a and R1234yf

Characteristics	**R12**	**R134a**	**R1234yf**
Molecular Weight	120.92	102.03	114.04
Boiling Point (°C)	-29.75	-26.07	-29.03
Ozone Depletion Potential (ODP)	1	0	0
Global Warming Potential (GWP)	8500	1300	4

Table 13 ASHRAE safety class for refrigerants

Safety group	Lower Toxicity	Higher Toxicity
Higher Flammability	A3	B3
Lower Flammability	A2	B2
	A2L	B2L
No flame Propagation	A1	B1

*A2L and B2L are lower flammability refrigerants with a maximum burning velocity of ≤ 10 cm/s

(b) R1234ze

R1234ze is a single component HFC refrigerant with a GWP of 6. It can replace R134a in new equipment where its lower volumetric capacity can be addressed in the design of the equipment. Like R1234yf, it is classified as A2L (low toxicity, lower flammability) so it will be subjected to similar barriers as R1234yf. This chemical is already produced on a commercial scale. It is anticipated that this refrigerant will be available when there is a market demand. This refrigerant produces efficiency levels comparable to R134a, in addition the same POE lubricant oil can be used for the compressor. As a new molecule, this refrigerant has a higher cost than R134a. This is mainly due to its different manufacturing process and economies of scale. It is expected that as production increases, the price premium will be reduced, but, it is likely to remain above the current costs of R134a.

(c) Ammonia (R717)

Ammonia has a zero ODP and zero GWP and offers excellent efficiency. Ammonia is described as low cost (less than $1/kg), but, generally demands the use of steel piping and components, because of a lack of suitable components for small capacity systems due to incompatibility with copper and its alloys, so smaller capacity systems can cost much more. As the capacity approaches and exceeds around 400-600kW, ammonia systems will become cost-competitive. With its safety classification of B2 (high toxicity, lower flammability), its use will need to be restricted in occupied spaces. Certain countries also have specific national regulations controlling its use. However, the use of ammonia refrigerants is still increasing, especially for large scale air conditioning systems.

(d) Carbon dioxide (R744)

A single component substance with a safety classification of A1 (lower toxicity, non-flammable), CO_2 has a zero ODP and a GWP of 1. CO_2 has a vapor pressure that is several times greater than other refrigerants, which is the biggest challenge to its application. The cost of CO_2 itself is very low, but, due to its high pressure, certain types of systems require more robust designs for pressure safety, which adds significantly to the cost.

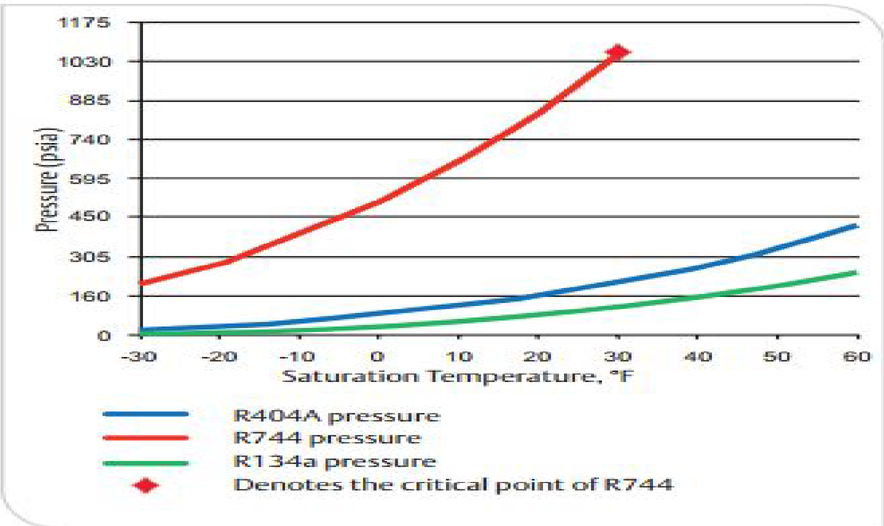

Figure 21 Pressure-temperature relationship comparison

(e) Hydrocarbons (HC)

Hydrocarbons (HCs) include three main pure refrigerants, R290 (propane), R1270 (propylene), and R600a (isobutene), and a number of blends. They are natural, nontoxic refrigerants that have no ozone depleting properties and absolutely minimal global warming potential. The thermo-physical properties of HCs lead to good efficiency at low discharge temperatures. These lower operating discharge pressures reduce the work that the compressor has to do; thus reducing wear and tear. There is less pressure on the mechanical parts and this reduces the possibility of leaks. This will extend the working life of the equipment. However, HCs have a safety classification of A3 (lower toxicity, higher flammability), and usage is limited due to maximum allowable charge sizes in occupied spaces. Building safety codes ban the use of flammable refrigerants in certain types of buildings. (As little as 4 ounces of hydrocarbon refrigerants can ignite due to sparks from lighting a cigarette).

Table 14 Comparison of traditional refrigerants and Hydrocarbon

Refrigerant	**HCFC (R-22)**	**HFC (R-134a)**	**Hydrocarbon**
Ozone depletion potential (ODP)	Low	Zero	Zero
Global warming potential (GWP)	High	High	Very Low
Flammability	No	No	Yes
Toxicity	No	No	No
Compatibility with system materials	Good	Needs different moisture sensitive oil	Good
Other issues	Will be phased out	Contamination in system is a problem	Flammable

(f) Solstice L40X (R455a)

As a replacement for R410a, L40X (GWP=146) has a relatively lower GWP than R410a (GWP=1924). It can cover most of the applications, such as A/C mode (0/65˚C), process chiller (-20/65˚C), and HP mode (-30/65˚C). The physical properties in compressors are similar to R22 and R290 (called the R22/R290 platform), and to the safety classification of A2L (lower flammability and lower toxicity). L40X should be seen as a new opportunity to replace not only R22/R407c/R290 but also R410a/R32 in the long term, as ODP=0, GWP<150, A2L and no injection is needed for high temp/pressure ratio.

C. Conclusion

Refrigerants have already gone through three generations of improvements, and several different considerations are made for toxicity, flammability, Ozone layer depletion potential, and global warming potential. The fourth generation will continue to drive both refrigerants and system innovation to meet stricter environmental and energy efficiency regulatory regimes in the future. Several HFOs (R1234yf and R1234ze) based solutions are available now for transition to ultra-low GWP while increasing safety baselines. Future development should focus on safety equipment and lowering costs.

3.2.4 Refrigerator Compressor Design

A. Group Introduction

Huayi Compressor Barcelona, S.L. is part of the Huayi Compressor Co. Ltd. group, and specializes in designing, manufacturing, and selling hermetic compressors and condensing units for the light commercial refrigeration market. Operating under the Cubigel Compressors® brand, the products are supported by European quality production. Located in Barcelona, the company exports more than 90% of its production and employs more than 400 people. The company focuses on a product innovation strategy dependent upon a strong R&D team, enhanced know-how, and more than 50 years of experience providing a broad range of solutions to the commercial refrigeration industry (Cubigel Compressors website). Cubigel Compressors offer a wide range of compressors from 2.4cc up to 34cc, working with most refrigerant gases, voltages, and for any type of application.

The history of the company begins in 1962 when Unidad Hermética was founded with the aim of producing compressors range L, P, and S under Tecumseh Products Co. (USA) license. After many years of presence on the world markets in 2012, the factory became a part of the world's largest Chinese producer Huayi Compressor Co., Ltd. - with annual sales of more than 30 million pieces of hermetic compressors for various applications (Cubigel Compressors website).

B. Green Cooling Solutions

The advanced design of Green Cooling ranges allows for a remarkable efficiency improvement. These ranges comprise High Efficiency, Natural Refrigerants, and Variable Speed Compressors. This last item is crucial to reducing refrigeration energy consumption, as the motor is electrically controlled. The high efficiency technologies improve the compressor COP by between 20% and 30%. It will increase the compressor’s performance and applications’ energy consumption by using natural refrigerants such as R290 and R600a with no direct effect on global warming. The VSC (Variable Speed Compressors) has the lowest energy consumption by adopting electronically controlled running modes and the efficiency is improved up to 50%. Also, improvements in the compressor designs follow the main characteristics (Huayi Compressor Barcelona, 2017):

(i) Separated suction: new suction muffler& new cylinder head

(ii) Reduced dead volume:

- New discharge valve assembly design
- Discharge port optimization
- Reduction of piston chamber

(iii) Electrical motor: New motor winding design & lamination material improved

C. Refrigerant Trends for Compressors

Following the phase out of CFCs due to the Montreal Protocol in the 1900s, refrigerants HFC-134a and HFC 404a were mainly applied in refrigeration systems more than 80% from 1997 to 2014 as shown in Figure 22. Following the Requirements of the 2014 EU fluorinated greenhouse gas (F gas) regulations, including the phasing out of HFCs and product -bans, some sustainable alternative refrigerants for refrigeration compressors with low GWPs and toxicity levels were promoted to over 20% since 2017, including HC (hydrocarbon), HFO (hydro-fluoro-olefins), and R744(carbon dioxide).

Cubigel's R&D team has diligently and successfully worked on an environmental alternative – with no direct contribution to global warming - and reducing energy consumption by using natural refrigerants with no greenhouse effect (R290) and developing High Efficiency compressor ranges. Propane (R290) has no direct contribution to global warming, and when used in an application, its energy consumption is around 12% to 15% lower than a similar application with R404A. Additionally, propane has better dynamic behavior, showing a lower increase of energy consumption with increasing ambient temperatures.

R290 compressors offer a higher cooling capacity and COP, allowing energy-saving consumption with smaller displacement. The major environmental benefits are obtained combining the use of the R290 with the design criteria of high efficiency range compressors. These compressor models, in their more advanced versions, can save up to 35% of energy when compared to standard efficiency series of R404A, thanks to very flexible asynchronous motors that can adjust to different energy consumption levels by connecting a permanent capacitor. The light commercial compressors fit the previous refrigeration trends are shown in Figure 23 for comparison among standard types, high efficient types, variable speed types, and up to date variable speed compressors for HC refrigerants. With the introduction of the best and most complete Green Cooling Range for more sustainable applications, Cubigel Compressors takes care of the environment and contributes to the reduction of the CO_2 emissions to the atmosphere.

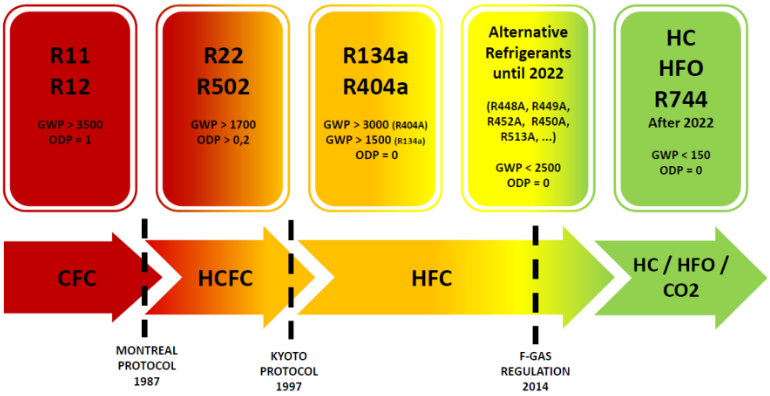

Figure 22 Evaluation process for refrigerant trends in refrigeration applications

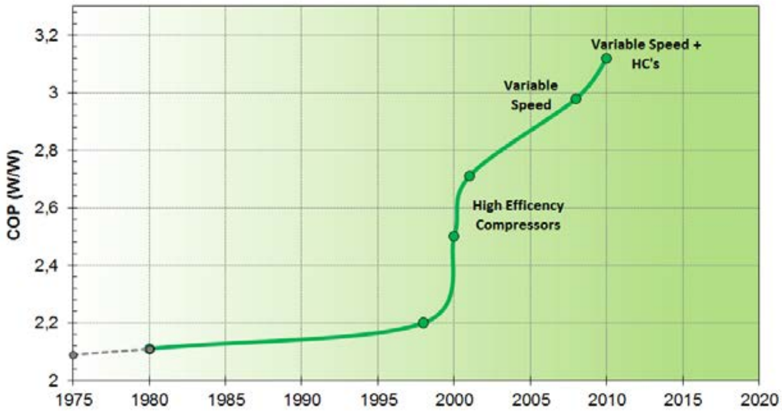

Figure 23 Light commercial refrigeration trends for Cubigel's compressors

Currently, the importance of protecting the environment is clear, and the effects of refrigerant leakages on global warming and climate change have become more evident. For these reasons, fourth generation refrigerants are necessary. Due to the high GWP of the HFCs, whose emissions are controlled under the Kyoto Protocol, hydrocarbons (HCs) are increasingly being used, such as R290 (propane) and R600a (isobutene), both of which have zero ODP and a GWP of 3. Huayi Compressor Barcelona follows the refrigerant trends and is committed to developing alternatives to refrigerants with high global warming potential, such as natural refrigerants (R290 and R600a).

D. Case Study for HFC-134a vs R-600a

Cubigel shared experiences with testing an existing refrigerator using an efficient R600a compressor, which allows up to 40-60% energy savings in an energy consumption test compared to refrigerant R134a as shown in Table 15 for the cold appliance characteristics (Huayi Compressor Barcelona, 2017). The focus of this case study was the conversion of an R134a refrigeration system of an existing refrigerator to use a natural refrigerant (R600a) and demonstrate that the converted unit can meet all the performance requirements. Performance of the retrofitted system was optimized by capillary tube size selection and reducing the refrigerant charge amount. The redesigned machine had only 20g of R600a refrigerant charge compared to 40g of R134a. The annual energy consumptions are 246 and 169 kWh for refrigerants R134a and R600a respectively as described in the test results of Table 16.

Table 15 Cold appliance characteristics for comparison of R600a vs R134a

APPLIANCE CHARACTERISTICS	
Original Refrigerant	R134a
Voltage	220-240V 50Hz
Internal net volume	177 Liters
Cabinet load	Fully loaded

Ambient temperature / RH	30ºC / 55%
Average internal temperature	+3ºC
Refrigerant Charge	40 gr (R134a) 20 gr (R600a)
Capillary tube	1 mm x 2,60 m (R134a) 0,9 mm x 3,60 m (R600a)

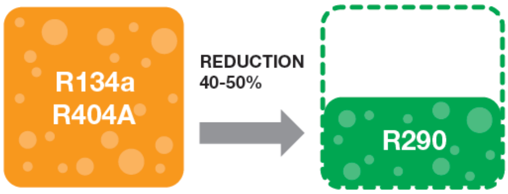

Figure 24 Test sample for comparison testing of R600a vs R134a

Table 16 Test results for refrigerator case study of R600a vs R134a

Data	R134a	R600a
Evaporating temperature (ºC)	-9.5	-9.8
Condensing temperature (ºC)	49.8	50.1
Inlet temperature (ºC)	3.2	3.1
Duty cycle (%)	49.5%	50.1%
Energy consumption (kW/24h)	0.673	0.462
Energy consumption difference vs cabinet with std compressor	-	**-31.35%**

Accumulated in 1 year		
Data	**R134a**	**R600a**
Total energy consumption (kWh)	246	169
Total energy consumption savings vs std (kWh)	-	77
Total energy cost savings (*)	-	7.55 €
Savings per day vs std (euro)	-	0.02 €
CO_2 emissions (kg CO2) (***)	111	76
CO_2 emissions reduction vs std (kg CO_2) (***)	-	**35**

(*) 0,098 €/kWh average energy cost in Europe

(***) Supposing 0,45kg CO2 emissions for each kWh

Natural Refrigerants are some of the most environmental friendly alternatives (excellent GWP). Natural Refrigerants applied in the most efficient appliances produced in Europe from last year with very positive results with a million units running. Natural Refrigerants systems do not require significant changes vs current HFC's and vs other ecological alternatives (CO_2) (Reasonable working pressures). The weak point of HC's is the limitation of 150 g charge per circuit, which includes most of the light commercial appliances charge. Restrictions are under discussion to extend the maximum charge, but, it is estimated to be only a middle term.

E. Case Study for Variable Speed Compressor Benefits

Cubigel's new variable speed platform offers the lowest applications' energy consumption by means of electronically self-adjusting the compressors to speed to the appliance cooling needs, while improving energy consumption by as much as 30%, as illustrated in Figure 25. Variable Speed Compressors are the solution for obtaining the maximum energy reduction, basically as the full compressor capacity is not always needed, and so this technology dynamically adapts the compressor's cooling capacity to the appliance needs by adopting an electronically-controlled running speed, optimizing the system's performance (Huayi Compressor Barcelona, 2017).

Its high efficiency mechanics and brush-less electrical motor, along with a system that regulates the speed in accordance with the needs of the system, makes the thermodynamic cycle more efficient when compared to a standard compressor as shown in Table 17.

Figure 25 Development Trends for Variable Speed Compressors with HC refrigerants

Table 17 Test results for refrigerator case study for Variable Speed Compressors

DATA	Fix Speed	VSC
Evaporating Temp. (ºC)	-30.1	-30.3
Condensing Temp. (ºC)	40.2	40.5
Internal Temp. (ºC)	-18.01	-18.44
Duty cycle (%)	52.6%	79.3%

Energy Consumption (kW/24h)	0.472	0.332
% in Energy Consumption	-	**-29.66%**

**For this case study --*

- *Domestic Freezer*
- *Volume: 182 liters*
- *Internal temp.: -18,0ºC*

3.2.5 System Design for Refrigerators and Freezers

A. Introduction of System Design for Refrigerator-Freezer

Refrigerators are a necessary appliance for every family, yet the energy consumption is about 15% to 20% of annual electricity consumption. Due to the impact of global warming and lack of fossil energies around the world, many countries have raised energy efficiency regulations for domestic refrigerators over the past decade. There are some useful methods to reduce energy consumption of refrigerators, including thermal insulation improvements, applying vacuum insulation panels (VIP), high efficient compressors, inverter controls, and refrigeration system optimization. There, the current contents of his presentation consist of the introduction to the general components and some available methods of improving EE efficiency, including inverter controls, thermal Insulation, and thermal-fluid simulation for system design. There were in total five examples from papers published by ITRI to conduct the design course.

Nearly 70 countries have policies in place to improve the efficiency of refrigerators sold in the market. Refrigerators are generally the first appliance that consumers purchase and are the first product that policymakers choose to regulate. Referring to CLASP's information, over 150 million new refrigerators were sold in 2015, and nearly 1.5 billion are already in use around the world (CLASP website). To keep refrigerators in homes in good condition, consumers not only need to know how to use them, but, also need to understand the basic principles of the refrigerator.

Refrigerators are intended for the storage of foodstuffs, with at least one fresh food compartment, and a Freezer is an appliance with only one or multiple freezing compartments. Refrigerator-freezers have at least one fresh food compartment and at least one freezer compartment. 'Frost free' does not mean no frost in the refrigerator, and actually the appliance is automatically defrosted with automatic disposal of defrosted ice-water. Heating with an electric heater is a common tool. For manual defrost products, the cold appliance runs the defrost function manually. The item 'refrigerate' means to make something such as food or liquid cold in a refrigerator in order to preserve it. Using all of the terms, definitions, and symbols, one can ascertain the details referring to the standards IEC 62552-1 to -3, 2015.

The participants may survey the ASHRAE Refrigeration Handbook (ASHRAE, 2010) to understand the design and construction of household refrigerators and freezers, the commonality of which are similar with the product class examples of the USA Energy Star (USA Energy Star website), such as refrigerator-freezers that include top-mounted freezers, side-mounted freezers, and bottom-mounted freezers.

The vapor compression cycle upon which refrigerators are based consists of a compressor, a condenser, a capillary tube, and an evaporator listed as the main components in the slide. Some not-in-kind refrigeration technologies researched in the literature are also listed in the presentation, including (Bansal, 2003):

- Absorption refrigeration
- Adsorption Refrigeration
- Magnetic refrigeration
- Malone cycle refrigeration
- Stirling/Pulse tube refrigeration
- Thermo-acoustic refrigeration
- Thermoelectric refrigeration
- Thermo-tunneling Refrigeration

The speaker did not introduce these technologies that are seldom used in common refrigerators at the seminar and only focused on the traditional technologies, especially on inverter controls, thermal insulation, and thermal-fluid simulation as means to improve energy efficiency.

B. General Components of Refrigerator-Freezers

The speaker illustrated the structure diagrams for an example of a refrigerator-freezer with top-mounted freezer, including the air side structure, different compartments, doors, defrost heater, air duct, and general components of a refrigerant compression system, as illustrated in Figure 26. A refrigerant compression system consists of compressor, condenser, expansion device, and the evaporator. A capillary tube is often used as the expansion device in a household refrigerator/freezer to flash the refrigerant from high pressure at medium temperature to low pressure with a temperature below -25℃ under a saturated state as shown in the refrigerant circulation diagram. In general, a suction line heat exchanger is designed to enhance the efficiency of a refrigeration cycle by soldering the capillary tube and the suction line together. A magnetic door gasket holds the door sealed but allows it to be pushed open from the inside. Frost is a porous medium composed of humid air and ice crystals and forms on the surface of the evaporator, which will reduce the refrigeration performance. For peak performance, periodic defrosting must thus be implemented. Fans play an important role in circulating the air across the evaporator and condenser to enhance the performance of the refrigeration system. The freezer control knob only controls the amount of air that flows into the fresh food compartment by a damper system.

All the thermodynamic states for an iso-butane R600a refrigeration cycle are also indicated in Figure 26, including the pressure and temperature of the refrigerant inside the piping system. The compressor is combined with both a motor and a pump, which moves the refrigerant through the piping system. Temperature sensors signal the compressor to start when the temperature inside the refrigerator rises above its set point. Cold air leaks out and warmer air leaks in because no refrigerator is completely airtight which causes the temperature to rise above its set point. As the compressor starts, it draws in the cold refrigerant gas in liquid form as it leaves the evaporator. Refrigerators use a type of refrigerant gas like R-134a or isobutene (R600a) that turns into a liquid at very cold temperatures: below -25 degrees Celsius at the evaporator. The compressor then puts pressure on the gas---compressing it. As the gas is compressed, its temperature goes up.

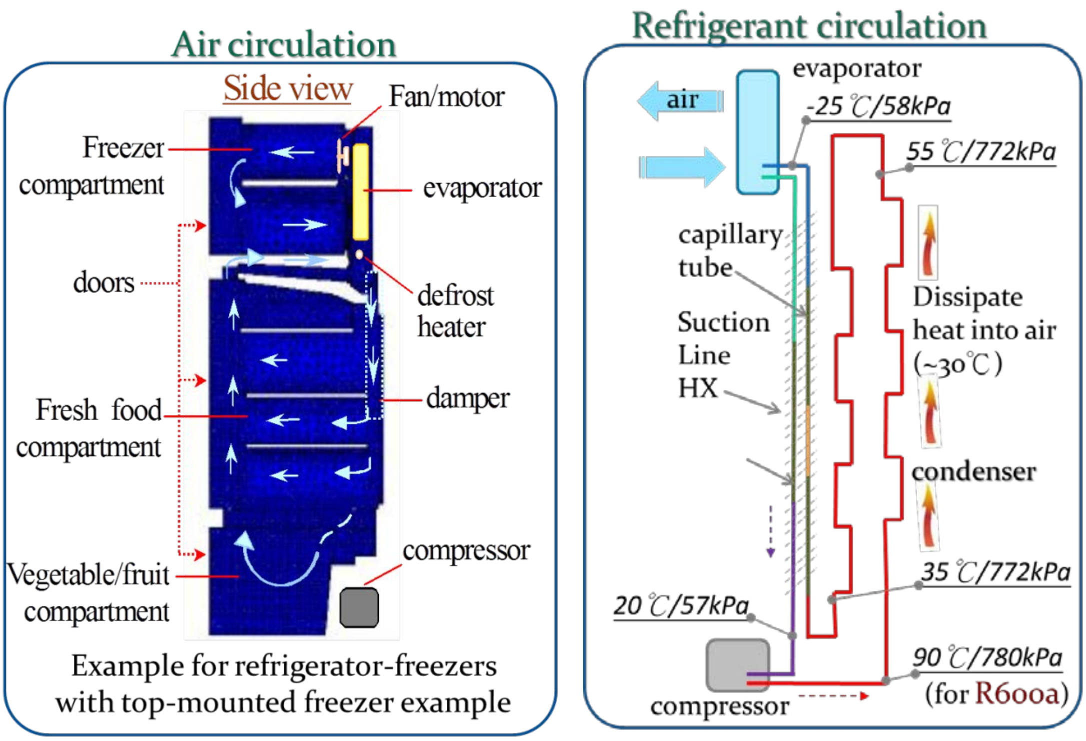

Figure 26 Introduction of general components of a refrigerator-freezer

The air circulation in the fridge cabinet is chilled by the evaporator and driven by a fan/motor. The minimum temperature of the evaporator's tube bundle is often below -28°C. The chilled air flows to the freezer compartment directly and is also divided to the fresh food compartment regulated by a mechanical damper.

Figure 27 shows the theoretical thermodynamic cycles for refrigerants HFC-134a & R600a, namely the pressure-enthalpy diagram to estimate the thermodynamic states for each component. It should be noted that the condenser and evaporator heat-transfer surfaces undergo pressure losses that also contribute to the overall compressor power requirement. Use the performance chart or test data for the compressor to determine the mass flow rate of the refrigerant cycling, and then use the thermodynamic and transport properties of the refrigerant to estimate the heat transfer rate and corresponding pressure drops of all the heat exchangers and piping under some specified operating speeds of the compressor.

Please survey the textbooks for fluid mechanics, heat exchanger design, two-phase flow, and some open literature to design the condenser or evaporator. There are also over 100 papers published regarding capillary tubes, so you can ascertain the methodology for capillary tube design.

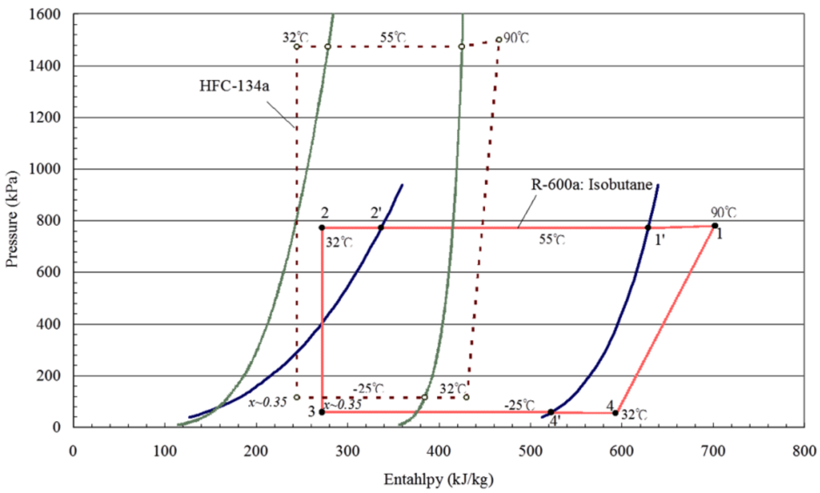

Figure 27 Theoretical thermodynamic cycles for refrigerants HFC-134a & R600a (Pressure-enthalpy diagram)

C. Inverter Controls

CASE 1

To reduce energy consumption greatly for refrigerators / freezers, novel inverter controlled technology for variable speed compressors with a brush-less DC (BLDC) motor was explored in the last decade, especially in Asia. The inner structure diagram and disassembled photo of a four-pole BLDC motor is shown in Figure 28. The energy-saving potential was evaluated to about 30% to 40% in some published literature. The DC motor inside the variable-speed compressor is driven by a digital signal processing (DSP) controller, one sensor-less power electronic circuit with pulse width modulation (PWM) regulation vs. its driving machine codes, a switching power supplier, and some peripheral communication circuits. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast rate with a power modulation system.

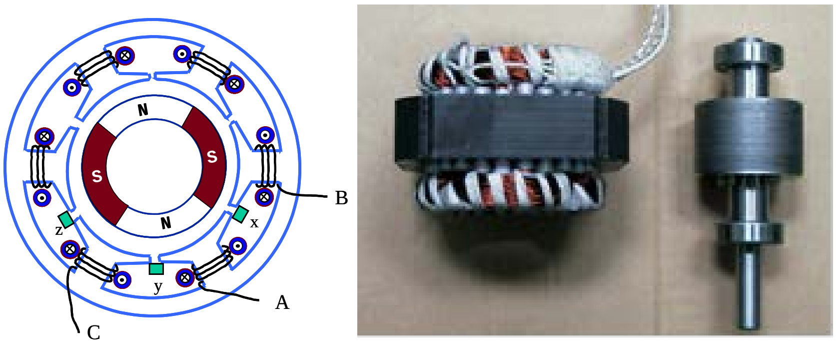

Figure 28 Inner structure diagram and disassembled photo of a four-pole BLDC motor

Using a six-step driving inverter drives the motor under some specified speeds with the pre-defined control sequence instruction, and the PWM waveform is described at the top diagram. The control sequence is following by Va, Vb, & Vc as indicated in Figure 29. This type of controller described previously is implemented as an inverter, and the product is generally named as a variable frequency refrigerators / freezers in Asia. The rotation speed of the compressor is usually controlled to within 1600~4800 rpm for normal operation. Temperature stability improves with a smart feedback control, and food freshness is maintained. Additionally, as the inverter-controlled compressor's turning ON/OFF frequency is reduced, this product's running life is also improved (Liu et al, 2003).

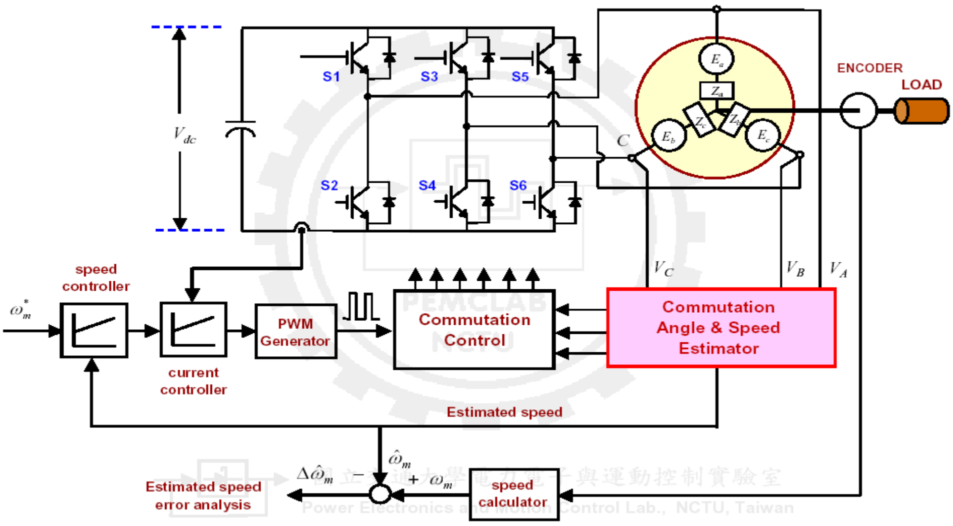

Figure 29 Control diagram for BLDC motor with PWM regulation

In general, the temperature of a refrigerator-freezer is maintained by turning it on and off with the thermostat relay of an AC compressor/motor, which causes cycling loss and reduces its energy efficiency. Under the off-cycle state, refrigerant inside pipeline of refrigeration system will flow through the capillary tube from the condenser at a high pressure & high temperature into the evaporator at low state. As the motor stops and the refrigeration system reaches equilibrium, and evaporator temperature rises due to pressure balance. When the system turns on again, warmer refrigerant vapor in the evaporator of the freezer compartment will exhaust additional refrigeration capacity during the starting instance. The system then needs to re-establish pressure potential between the condenser and the evaporator, until reaching the normal situation. The starting operation causes the refrigeration system loss of 3% to 17%, an energy consumption increase by 1% to 9%, and the COP is reduced by 5% to 25%, according to the literature.

ITRI has been studying inverter controlled refrigerators from as early as 2003, and has gradually established the fundamental skills (Liu et al, 2003). The room ambient temperature is fixed at 15°C and 30°C following standard CNS 2062, standing for winter and summer conditions, respectively. The relative humidity is set at 75%, and the storage temperature is set at -18°C ±0.5°C for the freezer compartment and 3°C ±0.5°C for the fresh food compartment. Refrigerators/Freezers ‘A’ and ‘B’ were tested under the same conditions concurrently in an environmentally controlled room as shown in Figure 30.

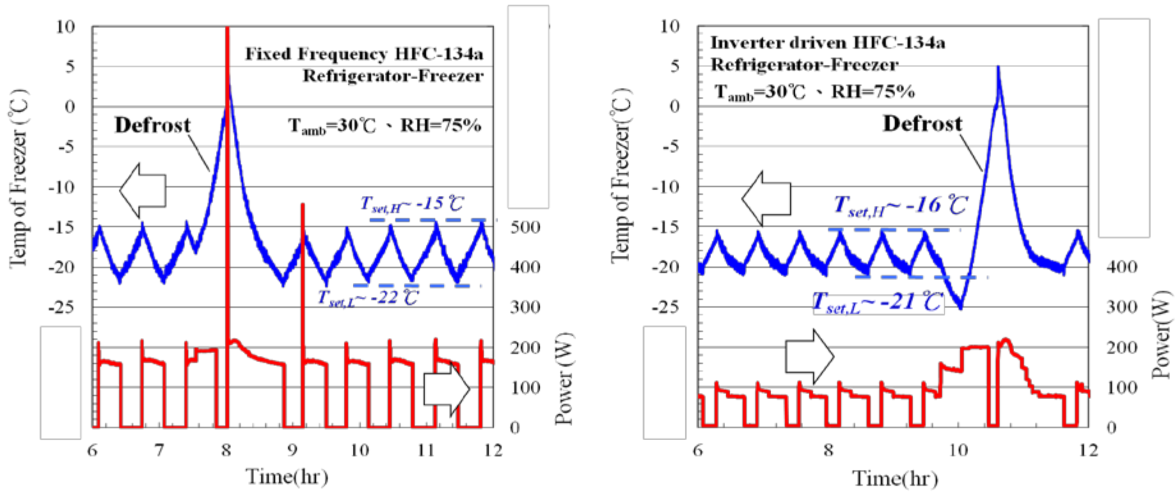

Figure 30 Freezer compartment temperature and power variation with time for fixed frequency and inverter driven products

From the test results, variable speed product ‘B’ had a higher energy efficiency than that of the fixed frequency product ‘A’ by 22% at a room temperature of 30°C. As the room temperature was set down to 15°C, the energy efficiency potential was raised up to 34%, as described in Table 18 (Liu et al, 2003).

Table 18 Comparison for Energy Consumption of Testing HFC-134a Refrigerators/Freezers at Ambient Temperature of 15°C / 30°C.

Ambient Temperature	30°C		15°C	
Type	Energy consumption (kWh/yr)	(B-A)/A	Energy consumption (kWh/yr)	(B-A)/A
Fixed Frequency Product ‘A’	932.5	-	474.0	-
Variable Frequency Product ‘B’	725.8	-22.15%	311.9	-34.2%

Case 2

Case 2 shows the implementation of an inverter-driven refrigerator-freezer using hydrocarbon isobutane compared to HFC-134a. To compare the performance between the refrigerants R-600a and HFC-134a, two inverter-driven HRFs of the same cabinet model were fabricated and studied experimentally. The gross inner volume for this cabinet model is rated at 560 liters with a top-mounted freezer of 133 liters. The specification and some results of the studied VF HRFs are shown in Table 19 (Chang et al, 2008).

Figure 31 illustrates the instant power and its corresponding freezer temperature variations with time for R-600a VF refrigerator No. A, including the defrost cycle. It is clear to indicate the step-change of power by the VF controller to reduce the fluctuation of storage temperature. One special function, named deep-cooling mode (from point d to e in the figure), is used to pull down the average storage temperature, and then suppress the rise of the compartment temperature after defrosting. The power capacity of the defrost heater is about 200W and operates for 23.6 minutes (from e to f) during defrosting.

Table 19 Specification and some results of the studied VF HRFs

Item	VF HRF A	VF HRF B	FF HRF C	FF HRF D
Refrigerant	R-600a	HFC-134a	R-600a	HFC-134a
Compressor	VF DC	VF DC	FF AC	FF AC
Power Input	110V/60Hz	110V/60Hz	110V/60Hz	110V/60Hz
Max. refrigeration capacity of the DC VF compressor	300W	300W	300W	300W
PU blowing agent	CP	CP	CP	HCFC-141b

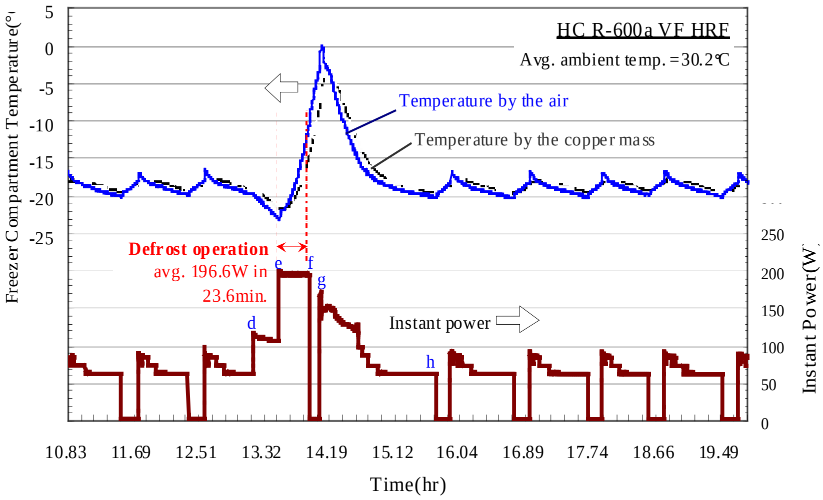

Figure 31 Temperature and power variation with time for R-600a VF HRF

By a steady test of 24 hours, the energy consumption of the R-600a variable frequency (VF) fridge was 1.426 kWh/day, which was 12% lower than that of the

HFC-134a VF one, which rated 1.62 kWh/day under the same temperature conditions. The baseline samples with fixed frequency AC compressors for HFC-134a and R-600a were also tested. The energy-saving potential for the inverter driven BLDC compressor is about 35% using refrigerants HC R-600a and HFC-134a, as described in the summary results of Table 20 (Chang et al, 2008).

Table 20 Summary Results of the Studied HRFs for Case 2

Item	VF HRF A	VF HRF B	FF HRF C	FF HRF D
Refrigerant	R-600a	HFC-134a	R-600a	HFC-134a
Compressor	VF DC	VF DC	FF AC	FF AC
Compressor capacity	300W	300W	300W	300W
PU blowing agent	CP	CP	CP	HCFC-141b
Freezer Temperature(°C)	-18.0±2.7	-18.1±2.8	-17.9±3.0	-18.1±4.1
Fresh Food Temperature (°C)	3.4±0.4	3.5±1.7	3.2±0.7	3.2±2.6
Energy Consumption(kWh/day)	**1.426**	**1.620**	**2.016**	**2.255**

D. Thermal Insulation & VIP

The energy consumption of a refrigerator-freezer is directly related to the cabinet internal load and cabinet thermal performance, where cabinet thermal resistance (insulation) and air leakage are the major factors affecting thermal performance. Energy measurement standards have traditionally ignored the cabinet heat load, where a well-insulated cabinet with a less-efficient refrigeration system might rank the same in an energy test as the one with less insulation but a more efficient refrigeration system.

PU (polyurethane) foaming material, as shown in Figure 32, is generally used in thermal insulation of HRFs. Via tests on PU foaming thermal insulation materials randomly selected from different positions of some HRF products, the thermal conductivity of this type insulation material applied in HRFs ranged between 0.018~0.022W/m-K.

Vacuum insulation panels (VIP) have been popularly applied in thermal insulation for HRFs for several years, especially in Japan, for what the composite insulation walls of HRF are combined VIPs jacked with PU foaming filler to form an excellent solution to decay of the thermal entrainment from the ambient. Figure 32 also shows a photograph of a VIP sample made by ITRI in Chinese Taipei. Typical structure of a vacuum insulation panel is made with a core material, a hermetic seal, and a humidity/air eliminator (getter).

Figure 32 Photos for PU foaming vs VIP

Case 3

Following the case study, as vacuum insulation panels (VIP) were applied, the energy saving was improved over 16% from the result of simulation and experiment. Although the average temperature would creep a little highly when using the multiple supply air vents compared to the simple pattern, and the air speed at vents would also slow down, the uniformity of air temperature was improved, as shown in Figure 33. Another benefit was that the temperature variation inside the cabinet was kept below 5°C near the door shelves. The design using the VIP insulation and multiple air supply vents attained the optimum for energy saving and uniformity of air temperature (Chang et al, 2001).

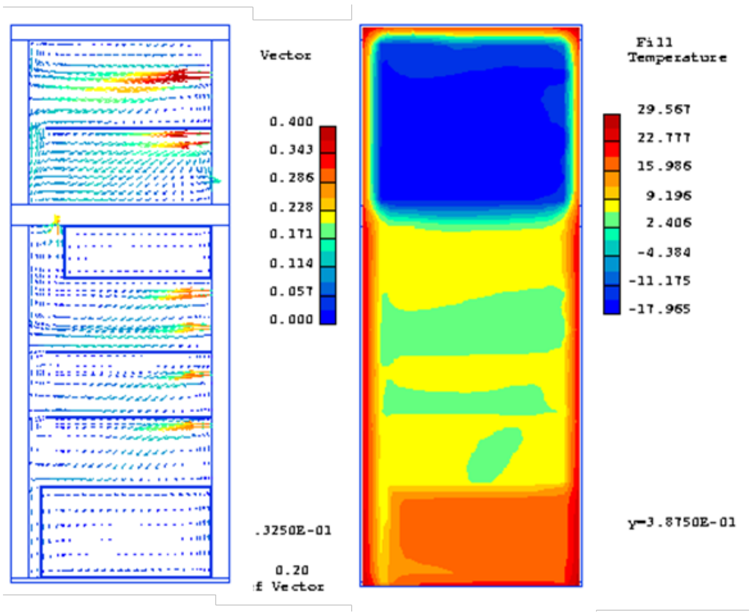

Figure 33 Simulation for airflow & temperature distribution on the cross section of y-axis

Case 4

There are several design options for improving the energy efficiency of household refrigerators/freezers, including increasing thermal insulation thickness for walls, improvement of thermal insulation material or applying vacuum insulation panels, using a high-performance compressor, and optimization of the refrigeration system. This study focuses on the design and development of inverter-driven refrigerators / freezers with vacuum insulation panels embedded inside the walls around the freezer compartment. The specific dimensions of applied VIPs are: 400mm×400mm for those on the freezer sides, 400mm×600mm on the top, 350mm×600mm for the door, and 300mm×300mm on the back. The energy saving has a potential of 10% following the standard testing procedure. The energy factor is 14.6L/kWh/month, which improves by 56% compared to that of the fixed frequency refrigerators / freezers of the same type. The comparison for different thermal insulation materials is described in Table 21 and Table 22 (Chang et al, 2006).

Table 21 Comparison for different thermal insulation materials

Model number of VF HRF prototypes	Model A	Model B	Model C
Thermal Insulation Scheme	pure PU foaming	PS VIP + PU filler	GW VIP + PU filler
Thermal conductivity value, k (W/m-K)	0.018~0.022	0.006 (VIP only)*	0.003 (VIP only)*1
Improvement of thermal insulation*2	-	66.7%	83.3%

Table 22 Energy Saving Effectiveness of VIP Variable Frequency Refrigerators/Freezers

Refrigerator/Freezer Type	Power consumption (kWh/month)	Power Saving Effectiveness	Power Saving Effectiveness
Pure PU Fixed Frequency HRF	67.65	-	Base-line
Pure PU VF HRF model A	51.20	Base-line	24.32%
PS-VIP VF HRF model B	45.69	10.76%	32.46%
GW-VIP VF HRF model C	45.97	10.21%	32.05%

E. Thermal-Fluid Simulation

It has been discovered that the performance of household refrigerators depends strongly on temperature and air distribution inside the storage chamber. Therefore, many subsequent investigations have been made to improve and to seek the optimal design for such household refrigeration systems. The most common ways for detailed investigations include Particle Image Velocimetry (PIV), and Computational Fluid Dynamics (CFD). However, the major problem associated with Particle Image Velocimetry is probably with its complex measurement techniques and it is difficult to de-couple the effect between air velocity and temperature (Yang et al, 2010).

Meanwhile, there were some numerical approaches or experimental studies regarding optimal designs of refrigeration systems. In practice, detailed information such as temperature or velocity distribution within a household refrigerator is unavailable in typical experimental studies. Hence, it would be easier to resort to numerical modeling due to its simplicity and comparative cost-effectiveness. Through the simulation, one can obtain related detailed temperature/velocity distribution subject to design concerns.

Case 5

This case described a numerical investigation of a top-mounted domestic refrigerator and an experiment is carried out with a real refrigerator for verification by ITRI (Yang et al, 2010). The simulations show that the air duct design and its locations may impose a detrimental role on the temperature uniformity within the refrigerator, yet the airflow is strongly influenced by gravity. It is also found that the refrigerating compartment possesses the worst temperature non-uniformity.

For remedying the temperature non-uniformity, a modified design incorporating the air duct design with appropriate locations of the inlet openings in the freezer and refrigerating compartment is proposed, as illustrated in Figure 34. Figure 35 shows the simulated temperature distribution amid the original and modified designs. The simulation results indicate a significant improvement in thermal uniformity with the modified design. Through these modifications, the maximum temperature difference and the root mean-square of temperature variation in the refrigerating compartment had been reduced from 7.2℃ to 3.6℃ and from 3.2℃ to 1.6℃, respectively (Yang et al, 2010).

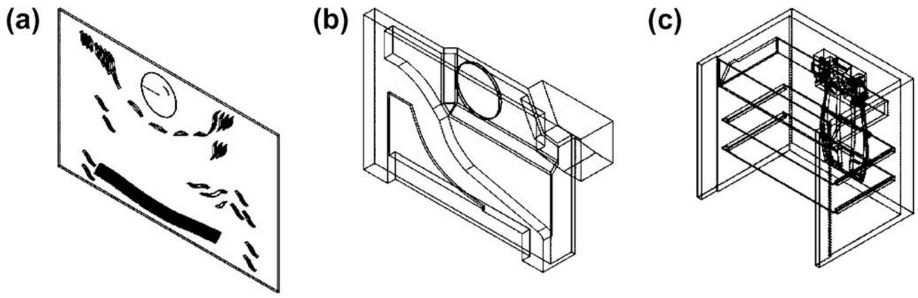

Figure 34 Modified air duct design of: (a) inlet of freezer compartment (b) evaporator and (c) refrigerating compartment

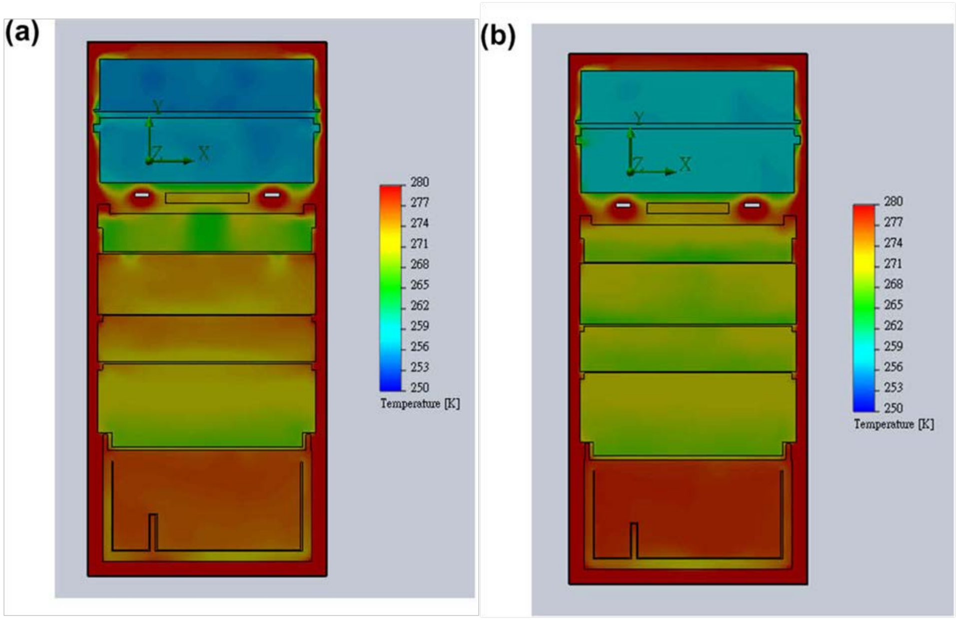

Figure 35 Temperature distribution at the symmetry plane of: (a) original and (b) modified air duct design in refrigerator

F. Conclusion

High efficiency technology has been developed by ITRI for more than two decades. Regarding the refrigerator / freezer technology for this project, ITRI carried out and completed the project of High Efficiency Technology Development for Industrial, Commercial, and Domestic Refrigeration funded by BOE of Chinese Taipei from 2002 to 2009.

ITRI has successfully developed inverter-driven refrigerators / freezers using refrigerants R-134a & R-600a as well as the corresponding key components, including reciprocating compressors, brushless DC motors, inverters and sensorless drivers, and vacuum insulation panels (VIP). Meanwhile, ITRI has also transferred these technologies to domestic manufactures, including Tatung, Teco, Kaltis, and Sampo companies.

The energy-saving refrigerator, VIP and inverter-control technologies developed at

ITRI continue to advance the refrigeration industry.

3.2.6 Outcomes of Technical Expert Group Meeting

This project distributed a questionnaire surveying the energy efficiency management and technology development issues of refrigerators to the members of developing economies and sought their participation in this project. The technical expert group meeting will help to collect and identify the actual needs of developing economies and provide the latest energy-saving knowledge to them. Therefore, the policy makers of the developing economies are expected to enhance their domestic EE management programs, accordingly. After the previous Energy Saving Technology Seminar for Refrigerator / Freezer Energy Efficiency Improvement in APEC Region, the 1st Technical expert group meeting of this project was hosted on the second day of the Seminar to discuss the outcomes of the previous survey study and the case studies of this project. The summary was derived from the presentation slides presented by the economic experts to share experiences on refrigerator energy efficiency promotion in the Energy Saving Technology Seminar at Taipei City on 17 November, 2017. Please find the details in the investigation report (ITRI, 2018). The outcomes for the Technical Expert Meeting are listed as follows:

(1) The project was able to meet the directives of the 2014 Ministerial Meeting to enhance cooperation among member economies, to build an information platform and to share R&D results.

(2) The work plan of this project is suitable to fulfill the objectives proposed by Chinese Taipei in terms of energy efficiency policy and technology evaluation and information sharing.

(3) In order to expedite the harmonization of refrigerator / freezer testing methods with IEC 62552/2015 among APEC region and to remove the trade barriers, it is suggested that the capacity build project of IEC 62552/2015 be implemented as soon as possible.

(4) It is suggested also that the round robin test of IEC 62552/2015 be executed to promote mutual recognition of refrigerator / freezer test reports among APEC region.

(5) Collect more information

(6) Dissemination

3.3 Workshop on Case Studies of Refrigerator / Freezer Design and Implementation under Energy Efficiency Regulations

The project team completed its assistance to the Project Overseer in a 1-day APEC Workshop on 9 April, 2018 during an EGEE&C (Expert Group on Energy Efficiency and Conservation) meeting at the Embassy Suites, Hilton Hotel, Washington, DC, titled

‘Workshop on Case Studies of Refrigerators / Freezers Design and Implementation Under Energy Efficiency Regulation (EWG 07 2017A)’. Four expert speakers and eighteen attendees from ten economies participated in this workshop as shown in Figure 36. After the 1st workshop, the team gathered representatives from each economy to the 2nd technical expert group meeting to discuss the resolution on the case studies. Chinese Taipei hosted this refrigerator workshop and corresponding technical expert group meeting to gather international experts from different economies to share EE promotion of refrigerator / freezer experiences under energy efficiency regulations. Five active participants with expertise in energy efficiency management of refrigerators funded by APEC attended to obtain more information at this event. The detailed agenda for the Workshop and Technical Expert Group Meeting on 9 April, 2018 is shown in Annex I.

Figure 36 Group photo for the 1st Workshop on April 09, 2018 in Washington DC

3.3.1 USA’s Experience

At first Expert, Dr Stephanie Johnson shared the regulatory history and trends of energy efficiency improvements for refrigerators in the US under the theme of “Consumer Refrigerators: Regulatory History and Trends”. The historical evolution trend of US consumer refrigeration appliance products is shown in Figure 37, refrigerators. The annual average electricity consumption decreased from approximately 1,700 kWh/yr at the highest level in 1974 to approximately 420 kWh/yr in 2015, as well as the equivalent volume increased from 18 cu ft (510L) to 22 cu ft (623L). A sharp drop shows that under the free market mechanism, energy efficiency control will not result in an increase in prices, but it will make consumers more secure. As shown in Figure 38, it is clear that the United States did not have any efficiency regulations before 1978. Afterwards, California first promoted energy efficiency regulations and adjusted the same twice. After 1990, all refrigerators in the United States were implemented with MEPS, and so far this has undergone three adjustments.

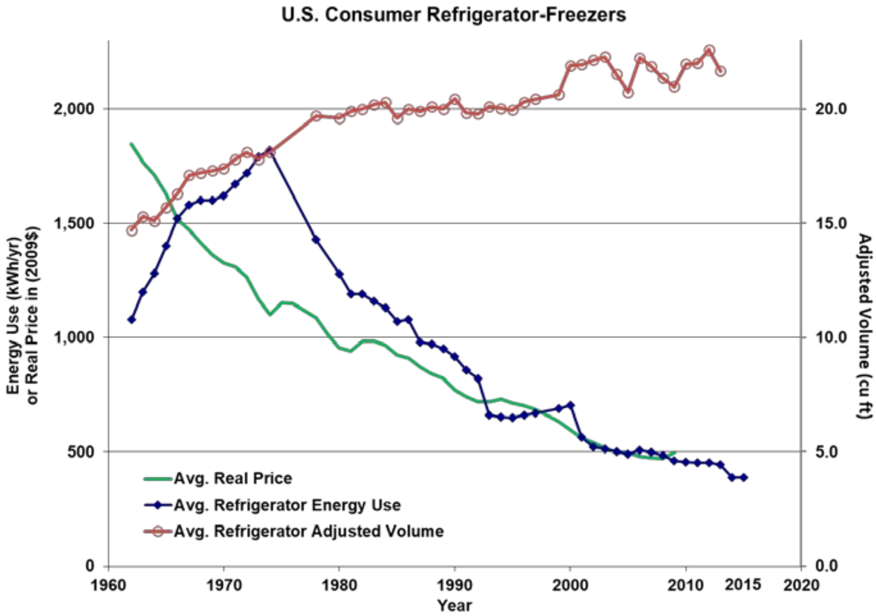

Figure 37 Consumer Refrigeration Products – Historical Overview in USA

California's Refrigerator Energy Efficiency Act of 1978, which calculates the allowable energy consumption benchmarks in terms of effective volume, includes refrigerator-freezers, freezers (automatic defrosting or non-automatic defrosting), and refrigerators. In 1980, the freezer top-mounted refrigerator-freezers were separated in categories, and different standards were applied for units with and without anti-sweat switches. In 1987, the energy consumption benchmark was calculated using the equivalent internal volume, the energy consumption benchmark for the mini-bar was established, and refrigerator-freezers based on configuration and through-the-door ice were also considered [30]. Since 1990, it has been implemented under the National Appliance Energy Conservation Act (NAECA standards), which is similar to the California standards, but, does not include compact products; the maximum energy use is about 10% lower than the California Act of 1978. In 1993, the United States Department of Energy enacted revised standards, and its energy consumption value was about 29% lower than MEPS in 1990. In 2001, the energy consumption benchmark was set lower again, which was approximately 21% lower than that in 1993, and compact refrigerators began to be included in energy efficiency regulations. The Department of Energy recently increased energy efficiency regulation standards. In 2014, the energy consumption value was revised down by 25% compared to 2001, and the functions of ice-making devices and built-in products were established into regulated classes.

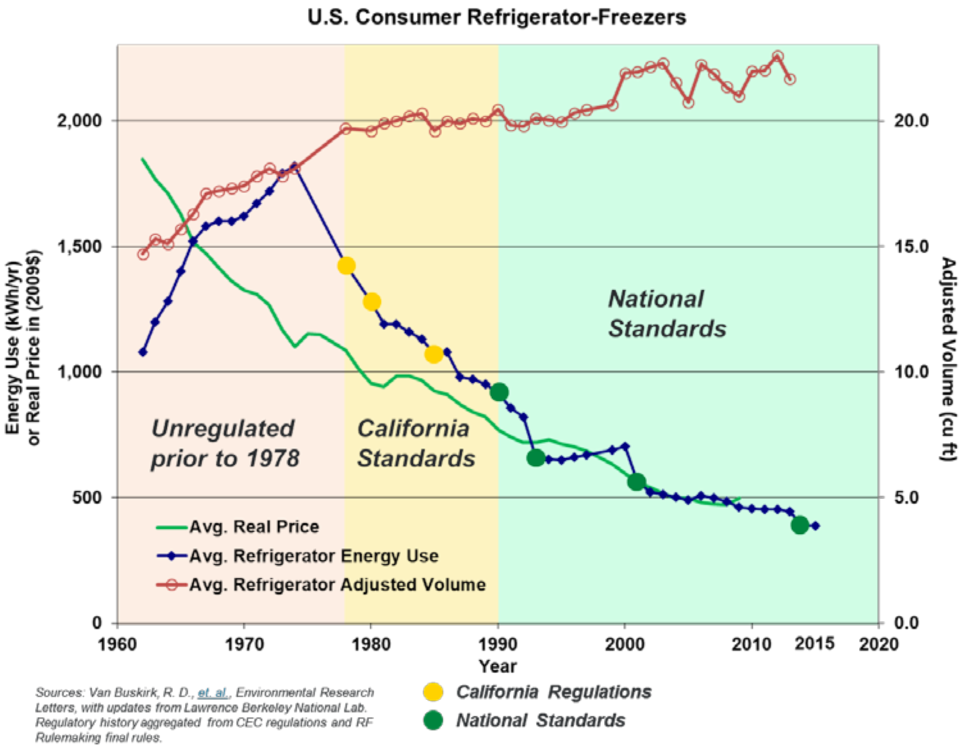

Figure 38 Consumer Refrigeration Products – Regulatory Review in USA

The United States still has other types of refrigeration appliances (MREFs, Miscellaneous Refrigeration Products) that are not included in the energy consumption regulations. Certain combination cooler refrigeration products currently have test procedure waivers and are required to meet existing refrigerator or freezer energy conservation standards, except as noted in the introductory note to the test procedure. Newly covered products (as of August 17, 2016) are defined as a consumer refrigeration product other than a refrigerator, refrigerator-freezer, or freezer. These include coolers (e.g., wine chillers) and combination cooler refrigeration products (products that combine a cooler compartment with a refrigerator or freezer compartment). The new procedures as of August 17, 2016 will be defined as "consumer refrigeration products" in the United States. Instead of defining the product name as a refrigerator, refrigerator-freezer, or freezer, these product ranges will cover coolers (wine chillers) or other combination cooler refrigeration products. Test procedures required for representations of energy use were revised on January 17, 2017 (LII, USA, 2017). New procedures follow the same general method in place for refrigerators and refrigerator-freezers.

For refrigerators, the rounding requirements specified in sections 5.3.5 and 6.1 of the Appendix to this Act (LII, USA, 2017) need not be used until the date of compliance of any of the revised energy-saving standards for these products. For combined refrigerated refrigeration products, manufacturers must use the test procedures in this appendix to indicate energy usage starting from the date of compliance of the energy efficiency standards for all of these products. For all other miscellaneous refrigeration products (e.g., coolers such as wine coolers), the manufacturer must use the test procedures in this appendix on or after 17 January, 2017 to specify all energy usage.

The United States will promote the new refrigerator energy conservation regulations in the future and these will take effect on 28 October, 2019. The Direct Final Rule was published on 28 October, 2016, and developed through a negotiated rulemaking process. The final deadline for the request for comments on the new version of the RFI (Request for Information) test program is 31 July, 2017. The new classification differences will be classified according to compact/full-size and free standing/built-in products. The refrigerator energy consumption benchmark formula will be 30% lower than the current California legislation benchmark, which will be higher than the highest energy consumption in the market. The products have a 75% reduction below current worst-performing units.

3.3.2 Japan's Experience

Japan's Top Runner Program, introduced in 1998 with revision of the Energy Conservation Law, is a set of energy efficiency standards for energy intensive products, such as home appliances and motor vehicles. As of 2017, the program involved 31 product categories. Products are included due to either their high energy or widespread use or their substantial scope for improving energy efficiency. Energy efficiency targets are set to be achieved within a given number of years on the basis of the most efficient model on the market (the 'Top Runner'). Top Runner Program is a maximum standard value system under which targets are set based on the value of the most energy-efficient machinery, equipment, and other items on the market at the time of the standard value establishment. The target fiscal years are set three to ten years ahead per product, reflecting certain product development periods and the outlook for future technical developments for targeted machinery, equipment, and other items. Achievement is evaluated with a weighted average method per manufacturer and category. The measurement methods should refer to domestic and international harmonization. If a standard has been already established, the measurement method should harmonize with the standard to the greatest extent possible. If no standard exists, it is appropriate to adopt specific, objective, and quantitative measurement methods based on actual usage of machinery, equipment, and other items (Yoshida, 2018).

The Energy Conservation Law regulates manufacturers to indicate items, generally including, 1) annual energy consumption or heat loss prevention performance, 2) product name and type, and 3) manufacturer's name, stipulated under the "Notifications". In 2000, the Energy Saving Labeling Program was established as a voluntary program based on Japan Industrial Standards (JIS). This labeling shows 1) energy saving symbol, 2) energy saving standard achievement rate, 3) energy consumption efficiency, and 4) target fiscal year, and it is actively utilized in manufacturers' catalogues. Since 2006, the Energy Conservation Law requires retailers to make efforts for information provision as an interface to consumers. The guideline instructs retailers to provide information using the "Uniform Energy-Saving Label" including multistage rating, expected electricity bill, and other information.

Surveys by the use of questionnaires are conducted by the Japanese Government. As a result of the survey, companies, that do not achieve the target standard, are required to report their improvements. In case improvement of the efficiency is insufficient even with the reported improvement activities, the Minister of METI offers recommendations to the company. Further, if such recommendations are not adopted by the company, the company name is made public and the company is ordered to follow the recommendation.

Concerning electric refrigerators under the Top Runner Program, manufacturers or importers whose manufacturing volume or importing volume (limited to shipping to domestic market) is 2,000 units (100 units for commercial refrigerators) or more. For some types of thermoelectric elements, residential absorption, and wine cellars are excluded from this Program. In recent years, electric refrigerators for residential use whose target fiscal year is FY 2010 and each subsequent fiscal year until FY2020, energy consumption efficiency is the annual energy consumption (kWh/year) measured as specified in JIS C9801 (2006). New Target FY2021 was set in FY2015 and energy consumption efficiency is measured as specified at JISC9801-3(2015). For commercial use, the target fiscal year is set as FY 2016 and each subsequent fiscal year, the energy consumption efficiency is measured as specified in JIS B 8630 (2009). In the target fiscal year and each subsequent fiscal year, energy consumption efficiency in each category shall be at or lower than the target standard value. The results of the Top Runner Program for refrigerators in Japan are tabulated in Table 23.

Table 23 Rule for FY 2010 and each subsequent for residential use in Japan

Category					Calculation formula of the target standard value
Category name	Refrigerator type	Cooling type	Rated internal volume	Number of doors in chiller section	
A	Refrigerator and refrigerator-freezer	Cold air-natural convection type			$E_1=0.844V_1+155$
B		Cold air-forced circulation type	Up to 300 liter		$E_1=0.774V_1+220$
C			Over 300 liter	1	$E_1=0.302V_1+343$
D				2 or more	$E_1=0.296V_1+374$

Note E_1 and V_1 express the following numerical values.

E_1: Target annual energy consumption (unit: kWh/year)

V_1: Adjusted internal volume (the figure is acquired first by multiplying rated internal volume of freezing compartment by either 2.20 for three-star type, 1.87 for two-star type, or 1.54 for one-star type, and then by adding the result to the rated internal storage volume excluding the freezing compartment. The obtained figure shall be rounded off to the nearest integer.)(unit: liter)

Table 24 Rule for FY2021 and each subsequent year (for residential use) in Japan

Category				Calculation formula of the target standard value
Category name	Refrigerator type	Cooling type	Rated internal volume	
A	Refrigerator-freezer	Cold air-natural convection type	—	$E_3=0.735V_3+122$
B		Cold air-forced circulation type	Up to 375 liter	$E_3=0.199V_3+265$
C			Over 375 liter	$E_3=0.281V_3+112$

Note E_3 and V_3 express the following numerical values.
E_3: Standard energy consumption efficiency (unit: kWh/year)
V_3: Adjusted internal volume (unit: liter) $V_3 = \sum_{i=1}^{n}(Kci \cdot Vi)$
Kci: Adjusted internal volume coefficient, *Vi*: Rated internal volume (unit: liter), *n*: Number of storage room

Storage type	Adjusted internal volume *Kci*
Pantry	0.38
Cellar	0.62
Refrigerator	1
Chiller	1.1
Zero-star	1.19
One-star	1.48
Two-star	1.76
Three-star or Four-star	2.05

Table 25 Rule for Target FY 2016 and each subsequent year for commercial use in Japan

Category				Calculation formula of the target standard value
Category name	Refrigerator type	Shape	Inverter controlled electric motor	
1A	Refrigerator	Vertical type	Y	$E_2=0.345V_2+86n_R+64d_R+345$
1B			N	$E_2=0.766V_2+86n_R+64d_R+106$
1C		Horizontal type	—	$E_2=1.12V_2+70n_R+34d_R+237$
2A	Refrigerator-freezer	Vertical type	—	$E_2=0.872V_2+86n_R+64d_R+186n_F+295d_F-113$
2B		Horizontal type	—	$E_2=2.43V_2+70n_R+34d_R+157n_F+157d_F-183$

Note 1 "Vertical type" refers to a front-opening type with an external height dimensions stipulated in JIS B 8630 (2009) over 1,000 mm.

Note 2 "Horizontal type" refers to a front-opening type with an external height dimension of 1,000 mm or less.

Note 3 E_2 is the numeric value of the standard energy consumption efficiency (unit: kWh/year)

Note 4 V_2 is the adjusted internal volume (unit: liter) calculated by the calculation formula given in the right column for each category name given in the left column in the following table, rounded off to the nearest integer.

d is the external depth dimensions stipulated in JIS B 8630 (2009)

V_R is the rated internal volume (unit: liter) of a chiller.

V_F is the rated internal volume (unit: liter) of a freezer.

Table 26 Results of the Top Runner Program in Japan

Items	Energy efficiency Improvement (result)	Energy efficiency improvement (initial expectation)
10. Electric Refrigerators (for residential use)	43.0% (FY2005 > FY2010)	21.0%
11. Electric Freezers (for residential use)	24.9% (FY2005 > FY2010)	12.7%

For the result and expected energy efficiency improvement of the Top Runner Program, the target FY2010 for residential use is 43.0% improvement from FY2005 level compared to the initial expectation of 21.0% and the target FY2021 is expected to see an improvement of 22.0% based on FY2014 level. For commercial use, the target FY2016 is expected to yield an improvement of 26.5% from the FY2007 level, and commercial freezer is expected to have a 22.5% improvement from FY2007 level.

Considering the potential technical improvements, three categories are provided with different design improvement elements shown in to fit the new target in 2015 for near future development. Target standard values (Top Runner Standard values) are determined by evaluating potential technical development toward target years, as well as adding the technical development to above maximum efficiency values.

Table 27 Potential technical improvements for refrigerators for new target in 2015

Category	Improvement element	Expected improvement rate
Category A Cold air-natural convection type	Improvement of fixed-speed compressor efficiency - Reduction of mechanical loss - Further low viscosity of refrigerating machine oil	1 – 3 %
Category B Cold air-forced circulation type Up to 375 liter	Improvement of variable-speed compressor efficiency - Reduction of mechanical loss - Further low viscosity of refrigerating machine oil - Further low-speed for input reduction Improvement of fixed-speed compressor efficiency - Reduction of mechanical loss - Further low viscosity of refrigerating machine oil	1 – 4 %
Category C Cold air-forced circulation type Over 375 liter	Improvement of variable-speed compressor efficiency - Reduction of mechanical loss - Further low viscosity of refrigerating machine oil - Further low-speed for input reduction Increasing coverage of vacuum insulation material	2 – 7 %

3.3.3 New Zealand's Experience

Since energy labelling commenced in 1986, Australia has had a mandatory product registration system for all products that are covered by Energy Labelling and MEPS. Initially this was administered at a state level, but is now national. New Zealand introduced mandatory regulations for product energy efficiency in 2002 and shares the same registration system and program requirements for nearly all products. Each model that is put on the market must be registered with its energy specifications (Thompson, 2018).

The Equipment Energy Efficiency (E3) program is a cross jurisdictional program through which the Australian Government, states and territories and the New Zealand Government collaborate to deliver a single, integrated program on energy efficiency standards and energy labelling for equipment and appliances. It is one of a number of programs implemented by the Council of Australian Governments (COAG) Energy Council. An Inter-Governmental Agreement provides the framework for national cooperation on the E3 Program. A similar arrangement has also been developed to ensure alignment with New Zealand. In New Zealand, the *Energy Efficiency (Energy Using Products) Regulations 2002* have a similar role and are administered by the Energy Efficiency and Conservation Authority (EECA). EECA is the government agency that works to improve the energy efficiency of New Zealand's homes and businesses, and encourages the uptake of renewable energies.

Covers household refrigerating appliances irrespective of the context in which they are used. Current exemptions – proposed to remain unchanged as follows:

- products which have a total gross volume of less than 60 litres designed exclusively for use in caravans and other vehicles
- portable products that have a gross volume of less than 30 litres
- products with a volume of less than 30 litres where the refrigeration function is secondary, e.g., cooled water dispensers
- products that have no options for connection to mains
- products that use technologies other than the vapour compression cycles
- wine storage cabinets
- Stand-alone ice-makers

Efficiency improvements in the US and EU have been achieved by incorporating mature technologies (such as vacuum insulation panels and more efficient compressors)that could also easily be incorporated into refrigerating appliances sold in Australia and New Zealand and would deliver considerable emissions abatements and energy cost savings to consumers (Thompson, 2018). The recent study by E3 for energy efficiency improvements for fridges and freezers in Australia is described by Figure 39, and in New Zealand in Figure 40.

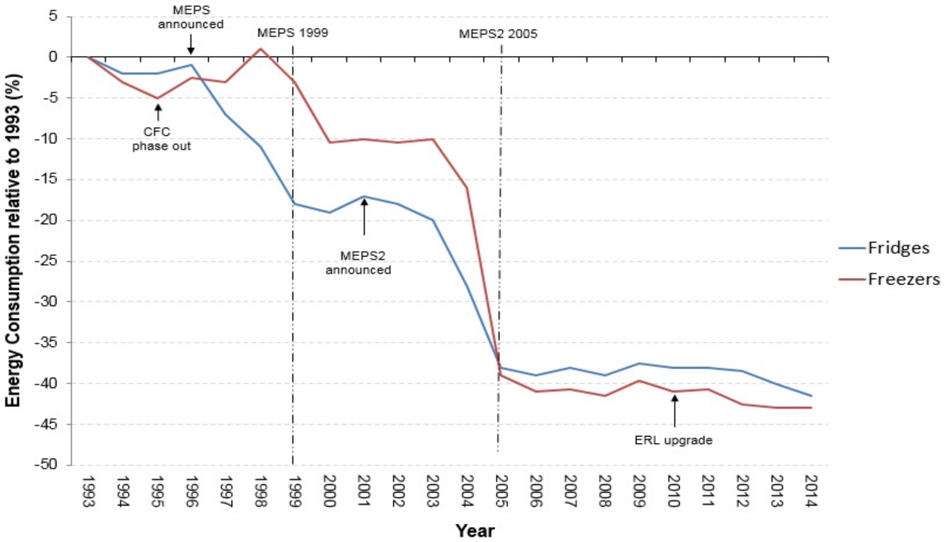

Figure 39 Energy efficiency improvements for fridges and freezers in Australia

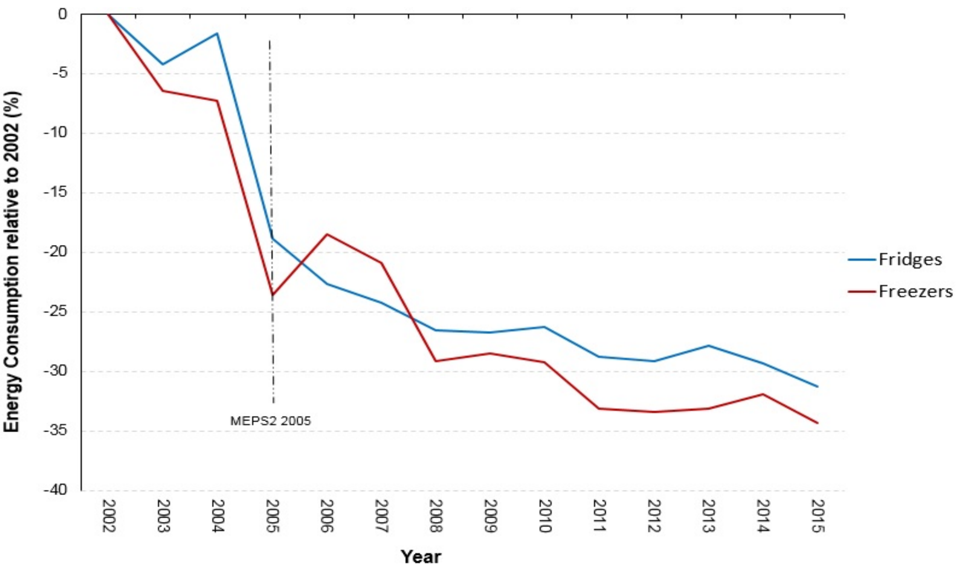

Figure 40 Energy efficiency improvements for fridges and freezers in Australia

3.3.4 Chinese Taipei's Experience

At present, Chinese Taipei has announced MEPS requirements for 22 product categories; and 51 product categories are authorized for participation in the voluntary energy efficiency labeling program; 14 categories of products, namely ductless air conditioners (including window and box air conditioner models), refrigerators / freezers, automobiles, motorcycles, dehumidifiers, and self-ballasted fluorescent lamps (commonly known as energy saving lamps) are included in the mandatory Energy Efficiency Rating Labeling system in order to provide guidance for consumers to select and purchase products with high energy efficiencies.

For domestic refrigerators and freezers in Chinese Taipei, there are two mandatory energy measures promoted in recent years, including the EE grade labeling program carried out in 2010 and the MEPS upgrade in 2011, which has a far-reaching impact on the local refrigerator and freezer industry. The 2011 MEPS benchmark value was improved to 70% of energy factor, and 41.5% of energy consumption compared to the baseline in 2003 for the equivalent volume above 400 liters as shown in Figure 41. The MEPS value reached the minimum level of grade 4 with a grade span of 7% in the 2010 EE grade labeling program for refrigerators in Chinese Taipei. After implementation of the EE grade labeling and the promotion of subsidy programs by BOE, the market share of grades 1 and 2 (high efficiency) products increased up to 97.4% in 2015. The annual energy consumption for domestic refrigerators in the last 7 years was estimated in Figure 42 based on the EE grade labeling database. In order to maintain market discrimination of EE grade labeling of refrigerators and reduce the market share for grade 1 & grade 2 to a reasonable percentage, ITRI carried out an upgrading study for EE benchmarking of MEPS and EE grade labelling from 2015 to 2016. The proposed energy consumption levels are shown in Figure 43.

By collecting and reviewing the market information and database of the EE grade labeling system, Chinese Taipei evaluated the promoting benefits for energy saving, and also analyzed the impact to the makers based on different grade spans. With a view towards achieving greater energy efficiency, the Bureau of Energy intended to modify the energy efficiency rating labelling requirements, but the MEPS would remain at 2011 levels, based on related national standards. After two vendor forums and one stakeholder meeting hosted by ITRI from 2015 to 2016, the draft requirements were finally confirmed by BOE. ‘Requirements on Minimum Energy Performance Standards and Energy Efficiency Grade Labelling and Inspection of Household Refrigerators and Refrigerator - Freezers’ was announced on the WTO/TBT platform on 20 October, 2016, as well as noticed in Chinese Taipei on 9 March, 2017. These revised regulations took effect on 1 January, 2018.

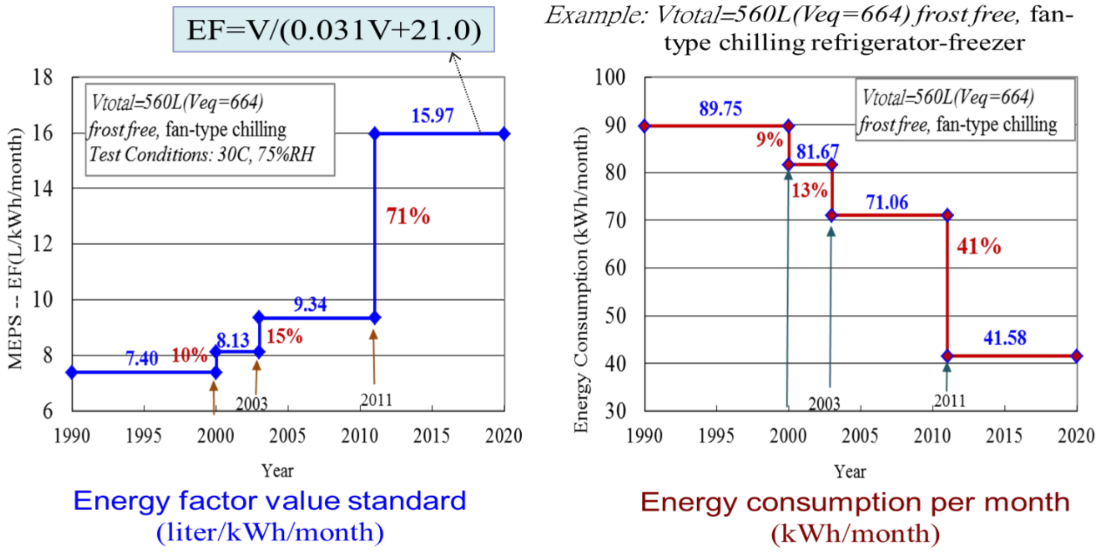

Figure 41 History development for MEPS in Chinese Taipei

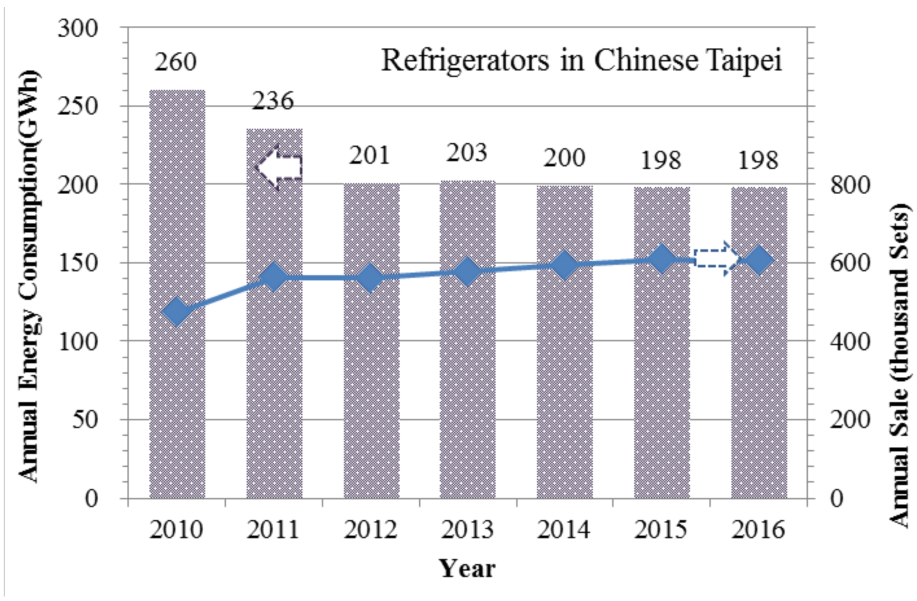

Figure 42 Annual energy consumption and market for domestic refrigerators in Chinese Taipei

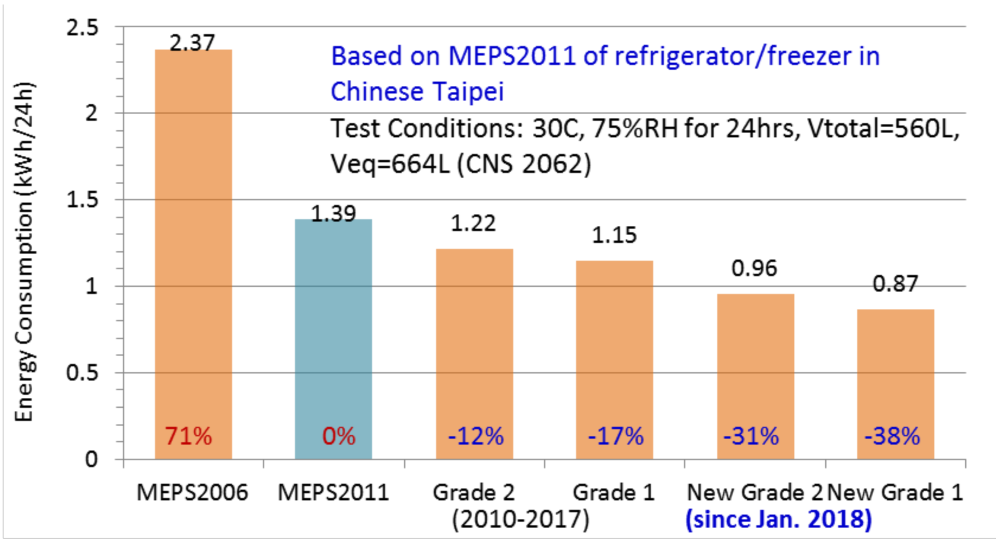

Figure 43 Comparison for MEPS & EE Labeling Standards of refrigerators in Chinese Taipei

In Chinese Taipei, high efficiency technology has been developed by ITRI for more than two decades. Concerning refrigerator / freezer technology, ITRI carried out and completed high efficiency technology development for industrial, commercial, and domestic refrigeration funded by BOE of Chinese Taipei from 2002 to 2009. The 2011 MEPS benchmark value was promoted to 70% of energy factor, as well as 41.5% of energy consumption compared to the baseline in 2003, based on the research efforts made by ITRI. High EE marking share has been increasing rapidly due to the EE grade labeling program as well as the incentive of subsidy programs administered by BOE.

3.4 Workshop on Refrigerator / Freezer Energy Efficiency Improvement in APEC Region: Review of Experience and Best Practices

The project team completed its assistance to the Project Overseer in a 1-day APEC Workshop held on 11 September, 2018 during the EGEE&C (Expert Group on Energy Efficiency and Conservation) meeting at the Le Méridien Hotel, Chiang Mai, Thailand, titled 'Workshop on Refrigerator / Freezer Energy Efficiency Improvements in APEC Region: A Review of Experiences and Best Practices (EWG 07 2017A)'. Eight expert speakers and 45 attendees from 12 economies participated in this workshop as shown in Figure 44. The project team also assisted in nomination and travel reimbursement for 4 active participants from travel eligible economies. After the workshop, the team gathered representatives from each economy to the technical expert group meeting to discuss the resolutions on the case studies. The detailed agenda for the Workshop and Technical Expert Group Meeting held on 11 September, 2018 is shown in Annex II.

Figure 44 Group photo for the 2nd workshop on Sep. 11, 2018 in Chiang Mai

3.4.1 Thailand's Experience

The first speaker from Thailand, Dr Supachai Sampao, from DEDE (Department of Alternative Energy Development and Efficiency, Ministry of Energy) shared EE (energy efficiency) management policy and tools for electric appliances, especially for household refrigerators. The EE management in Thailand classifies refrigerators by the number of doors; 1 door, 2 doors, 3 doors, 4 doors and more doors. Usually single-door refrigerators are small volume products, so they are divided into two small-categories with 100 liters. Refrigerators with multiple doors are classified with volume of 450 liters, and the compressors used include fixed-speed and variable-speed with inverter controls. The single-door refrigerators over 100L and the double-door ones under 450L are bulk products, and hold 80% of the market in Thailand. The market share of refrigerators with three doors or more is below 1%, as listed in Table 28. The EE regulations, the expected voluntary standard TIS 455-25XX Parts 1 to 3 will be issued around the 4th quarter of year 2018, and the expected mandatory standard TIS 2186-25XX will be issued around the 1st quarter and become effective in the 3rd quarter of year 2019. The draft criteria for new MEPS and HEPS of refrigerators and refrigerator-freezers for the previous specified standards were also introduced at the workshop.

The 2nd speaker from Thailand, Mr Pawatt Suwannakut, from EEI (Electrical and Electronics Institute) shared experiences with refrigerator EE promotion. Thailand has converted the refrigerator standard to ISO IEC 62552:2007 by the 2005 edition of ISO 15502. In recent years, the TISI TC48/8 technical committee has revised the standards according to the IEC 62552:2015 edition. The ambient temperature will be set as 32°C, and the load will be increased according to IEC standards. In addition to describing the refrigerator market and technology development in Thailand, he also introduced the difference between the new IEC standard and the old version, the process of implementing the new version of the standard in

Thailand, and the APEC regional refrigerator test standard. Finally, the speaker analyzed the data for MEPS, HEPS, and grading labeling drafts for Thai refrigerators. The annual power consumption distribution of the two-door refrigerators from 2012 to 2018 was taken as an example, as shown in Figure 45, which are mainly concentrated in Thailand. Annual power consumption for labeling two stars and three stars for the equivalent volume of 550 to 650 liter models is distributed among 600 - 800 kWh/year, which still indicates an opportunity to improve the energy efficiency in the near future.

Table 28 Market share for refrigerators in Thailand

Size/Volume	Proportion
1 door AV < 100 L	4.50 %
1 door AV ≥ 100L (3.5 Q)	46.26 %
2 doors AV < 450 L (15.8 Q)	34.11 %
2 doors AV < 450 L (INVERTER)	11.82 %
2 doors AV ≥ 450 L	1.45 %
2 doors AV ≥ 450 L (INVERTER)	1.25 %
3 doors AV < 450 L	0.28 %
3 doors AV < 450 L (INVERTER)	0.06 %
3 doors AV ≥ 450 L	0.11 %
4 doors	0.14 %

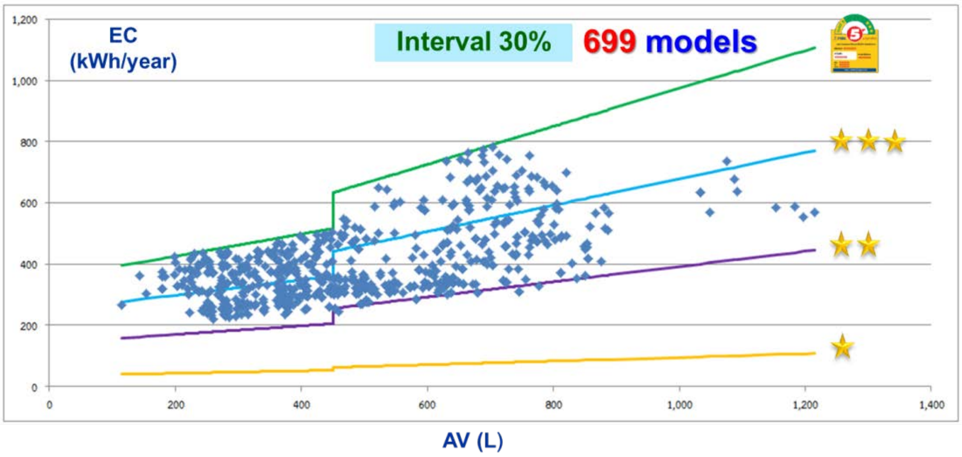

Figure 45 Annual power consumption distribution of double-door refrigerators from 2012 to 2018 in Thailand

3.4.2 Chinese Taipei's Experience

Firstly, speaker Mr Tony Wen-Ruey Chang of ITRI introduced the history of EE promotion of refrigerators in Chinese Taipei, including MEPS, voluntary energy conservation labels, and the mandatory EE grade labeling system since 2010. In 2011 the MEPS benchmark EF values were greatly improved by 71% for equivalent volumes above 400L, and improved by 57% for equivalent volumes below 400L, the corresponding annual power consumption was reduced by 41.5% and 36.5%, respectively. With the Government's energy-saving product subsidy programs, high efficiency refrigerators were successfully motivated in the market. The market share for Grade 1 and Grade 2 refrigerators reached 97.4% in 2016, which also conducted the upgrade for the EE grade labeling benchmark, later. The revised Refrigerator power consumption standard and power efficiency grade labeling, method, and inspection method regulations became effective on January 1, 2018. The grade span is enlarged to 18% from 7% for refrigerator products, and 15% from 7% for other categories. Therefore, the new Grade 1 can save energy by 21% compared to the old Grade 1. Through a review of research on refrigerators, Mr Chang also described several EE technologies and design concepts to fit the new standards since 2018, including

- Cabinet improvement: thermal insulation, magnetic seals
- Improvement to the refrigeration system
- Mechanism improvement: defrosting, temperature control
- Minimal thermal stratification in compartments
- Harmonization of Energy Efficiency Test Methods of Refrigerators

The second speaker from Chinese Taipei, Mr Peng Chi-Tseng from the Household Appliances Group, TECO Electric & Machinery Co, Ltd, gave a brief introduction regarding the TECO group and shared the efforts for smart life ECO by TECO, including heavy industrial products, green electric machines, systems & automation products, electrification products, power business group, and household appliances. According to TECO's survey, the freezer top-mounted refrigerators are the most popular in Chinese Taipei, but the preferences in different regions of Asia are not the same. For example, Japan is dominated by multiple-door refrigerator-freezers and South Korea prefers side-by-side products. Most Southeast Asians buy double-door refrigerators.

In response to Chinese Taipei's implementation of the new grading labeling program in 2018 and in line with consumer demand, TECO took the recent development of high-efficiency new-type refrigerators as an example. The efficiency must be increased by 39% to meet the new Grade 1 benchmark, and the energy-saving design measures should be developed, as shown in Figure 46, including optimized refrigeration system design, cold air circulation and air duct design improvement, smart energy-saving controls, and minimization of heat leakage, while strengthening the scheduling and inspection of the refrigerator manufacturing line, including inner and outside cabinet modeling process, refrigeration system vacuuming and refrigerant filling, PU foaming control, and uniformity inspection, and finished product inspection, to ensure compliance with the design goals, as shown in Figure 47.

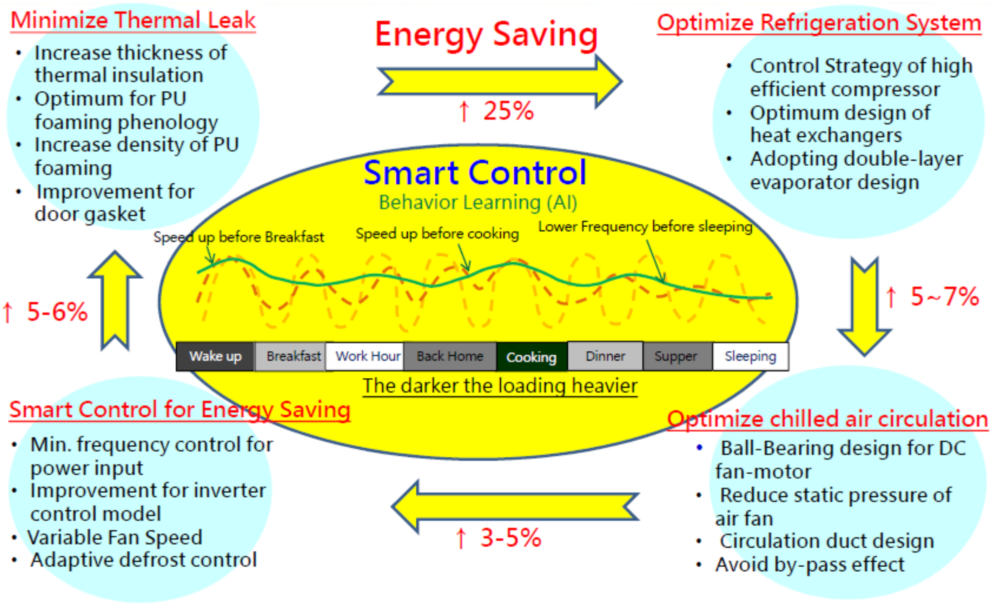

Figure 46 TECO's energy-saving design counter-measures in response to the new 2018 refrigerator Grade Labeling update in Chinese Taipei

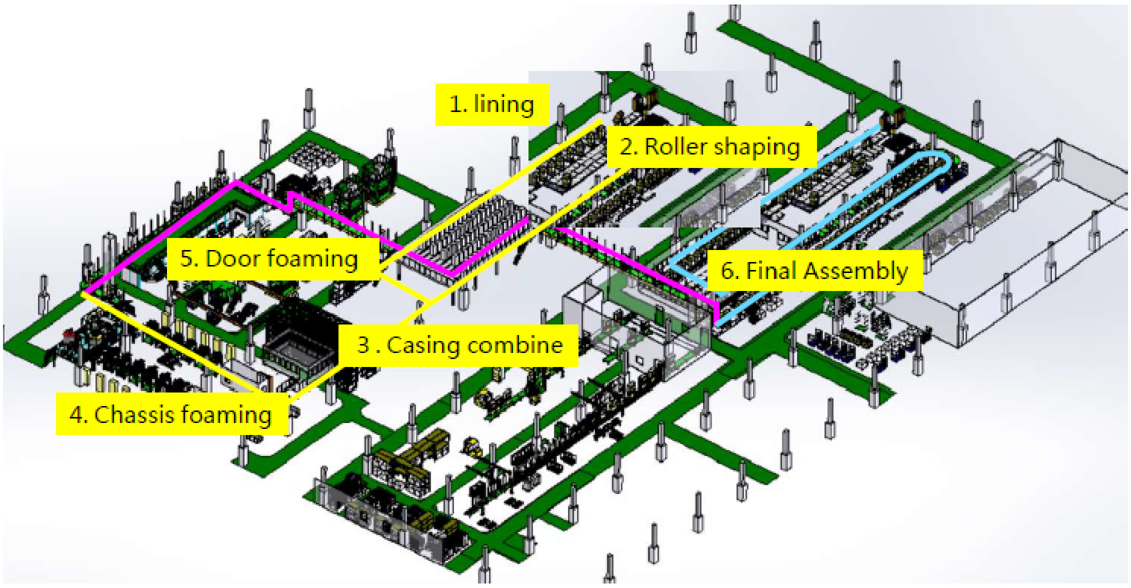

Figure 47 TECO's plan for inspection of quality insurance in response to the new 2018 refrigerator Grade Labeling update in Chinese Taipei

Mr Heng-Chun Lee, from the Refrigerator R&D Department AP Development Center, Appliances Domain Business, Panasonic Co. in Chinese Taipei, was the 3rd speaker from Chinese Taipei to share eco design ideas to improve refrigerator energy efficiency. He started with the issues of environmental pollution, global warming, health and ecological hazards, and then introduced the eco-environmental concept "eco ideas" of Panasonic in Chinese Taipei, and shared the EE promotion experience of one refrigerator model as an example to face Chinese Taipei's increasingly high efficiency requirements, since the MEPS launched in 2001 and the grade 1 benchmark in 2018. This product NR-D619NHGS has increased by 170% to meet the latest Grade 1 requirements. The efficiency of the old model is increased, involving many design techniques, as shown in Figure 48 and Figure 49. In this case, a high-efficiency evaporator and a high-efficiency condenser are used in the refrigeration system to improve efficiency by 3% and 2%, respectively. The air circulation resistance was reduced by the airflow duct modification and a low-power DC fan motor to increase efficiency by 3%. Adapting a high-efficiency compressor charged with environment friendly refrigerant improved the efficiency by 5%. The efficiency and cost for different components are not the same, and are often combined with construction or mold design changes, which will inevitably increase manufacturing costs. The redesigned refrigerator prototypes were made under trial production in small batches, and then long-term performance tests were conducted to assess the efficiency achievement.

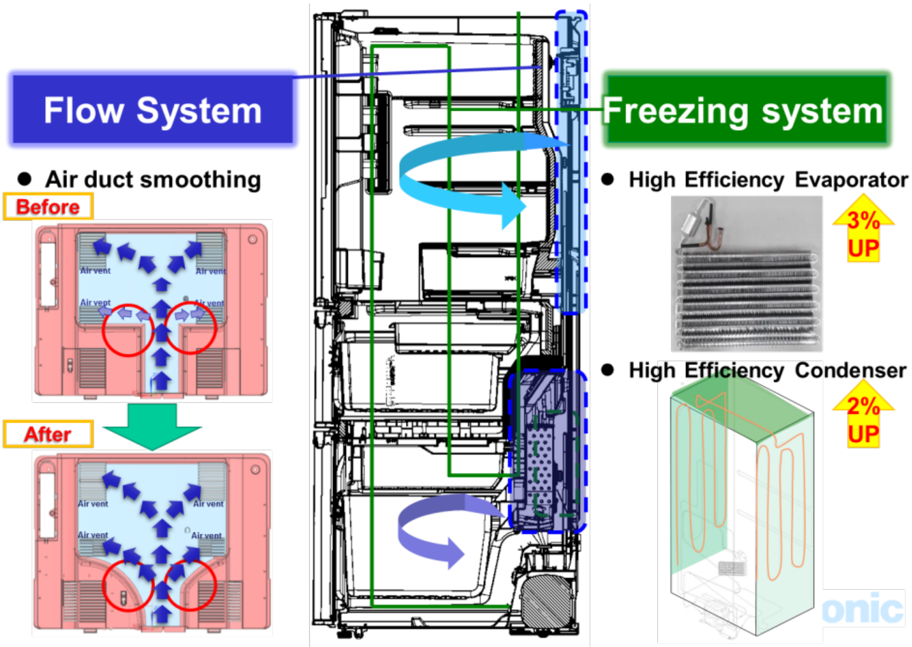

Figure 48 Panasonic's energy-saving design ideas Pt.1 in response to the new 2018 refrigerator Grade Labeling update in Chinese Taipei

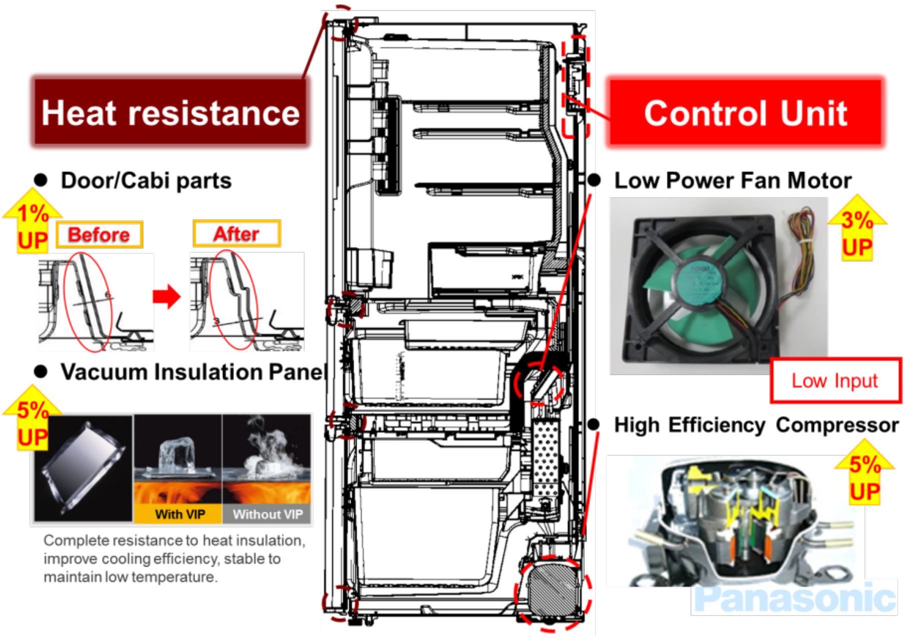

Figure 49 Panasonic's energy-saving design ideas Pt.2 in response to the new 2018 refrigerator Grade Labeling update in Chinese Taipei

3.4.3 China's Experience

China's expert Dr Li, Pengcheng, from China National Institute of Standarization, shared the energy efficiency standards for appliances and equipment in China. Firstly, he described why the standards work for EE promotion, including (1) technical consensus to improve efficiency and effectiveness, (2) leading and harmonized basis for sustainable development and resource saving society, (3) basis for government's scientific, well-organized and quantified administration, (4) tools for improving productivity, measuring energy efficiency and evaluating energy use.

China has initiated 100 energy efficiency promotion programs so far. In 2012, NDRC (National Development and Reform Commission of China) and SAC (Standardization Administration of China) launched the 100 Energy Efficiency Standards Promotion Programs to develop or revise more than 100 key standards for energy conservation in two years. The main contents of the program include energy efficiency standards and energy consumption norms. By 2015, more than 200 standards were published. It is estimated that 22 energy efficiency standards can save 79 billion kWh and 49 norms can save 127 million TCE (Tons of coal equivalent).

He explained the market transformation theory for energy efficiency with concepts of leader, repeater, and laggard. (a) Leading Edge: Leading the market share of high-efficiency models in the market with R&D innovation; (b) Mid Market: By developing performance test standards, the product information and its selling price are fully exposed to reduce the resistance promoted by high-efficiency products; (c) Laggards: Using performance standards expose energy efficiency information, so that consumers will not want to buy inefficient products, and even use laws to ban sales and to eliminate inefficient products. Dr Li also took the experience of the United States in promoting energy efficiency regulations for refrigerators for forty years. For example, the implementation of energy efficiency standards can indeed achieve the expected energy-saving goals, and the average capacity of US refrigerator products is increased by mass production and economic benefits. Both the price and the energy consumption can be reduced.

In recent years, efforts have been made to shift the market to high-efficiency products with energy efficiency standards in China, as shown in Figure 50, by using MEPS to eliminate inefficient products, and EE Labeling evaluation (Grades 1 and 2) or top runner. The system encourages high-efficient products to improve the overall energy efficiency level. Figure 50 shows the process of promoting energy efficiency standards in China. China started MEPS for 9 products in 1989 and then gradually expanded these to lighting, industrial products, and commercial products. In the past decade, the energy efficiency standards for several office appliances have been promoted. The popularity of refrigeration and air conditioning products is still increasing, and the numbers for the refrigerator models and their enterprises are the largest in the EE program. The number of products with Grade 1 is up to 73% of the total market, and that of Grade 2 products is about 15%. The market share of high efficient products has reached 90%.

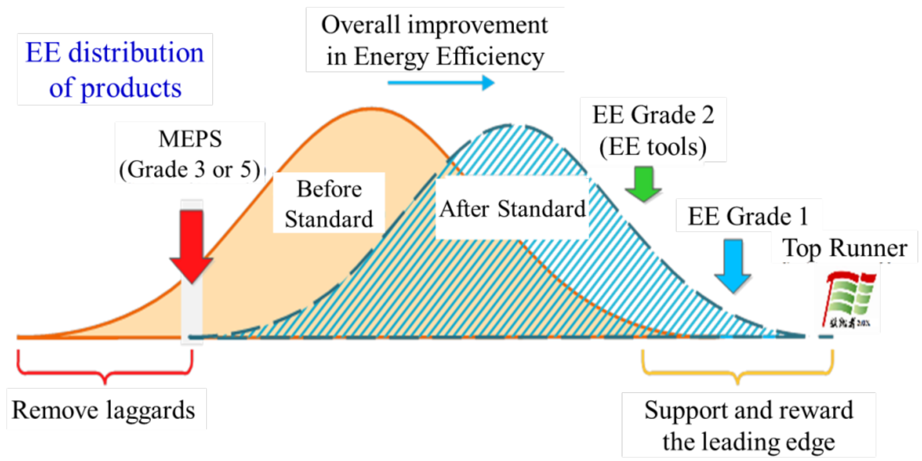

Figure 50 Impact of EE standards on distribution of products in the marketplace of China

3.4.4 Viet Nam's Experience

Viet Nam's expert, Ms Doan Thi Thanh Van from VSQI (Viet Nam Standards and Quality Institute), shared the refrigerator EE promotion experience, focusing on the outline of the labeling program in Viet Nam by 2015, policy changes, and some issues to be met in the future. There are four major brands of refrigerators in Viet Nam, including Aqua, Panasonic, Sharp, and Sanyo, which account for two-thirds of the market. Funiki is the only local manufacturer with a market share of only 4%, while the refrigerators assembled domestically take 30-40% of market. The type of 2-door refrigerator with freezer compartment with a volume of less than 500 L is the main product on the market with 74% to 80% for the market share. The second type on the market is a 2-door refrigerator with a volume of less than 300L, usually charged with refrigerant HFC 134a. Some refrigerators with inverter controls or charged with hydrocarbon HC 600a (iso-butane) are about 5% to 7% of the market, now. In 2015, the annual retail sales was about 2.12 million sets with an annual growth rate of 10% to 20%, so EE management is very important for this fast-growing product.

Viet Nam's refrigerator MEPS started in 2007 and regulate the products with effective volume of less than 1,000L, which was amended twice in 2013 and 2016, respectively, with the annual power consumption benchmarks shown in Figure 51. The high-efficiency energy efficiency (HEPS) benchmark is also adjusted as shown in Figure 52. The latest information and details are announced as the Viet Nam Energy Labeling Program TCVN 7828:2016 and TCVN 7829:2016 scope with refrigerators, refrigerator-freezers, and freezers with capacities of up to 1000 L, refrigerated by natural or forced convection, with exemption for absorption refrigerating equipment, showcases, specific refrigerating equipment, such as in used industry and medicine. The energy efficiency rating will be evaluated by the following formula:

$$R = \frac{E_{max}(MEPS)}{E_{year}} \quad (1)$$

E_{year} – is energy consumption per year (Wh/year)

E_{max} – is maximum energy consumption per year (Wh/year)

R – energy efficiency ratio

Viet Nam’s Energy Efficiency Rating is listed in Table 29. The performance test for the refrigerator is carried out according to IEC 62552:2015. The daily electricity consumption at 32 °C is measured and then calculated. E_{daily}, E_{aux} and $E_{load\ processing}$.

$$E_{year} = E_{daily} \times 365 + E_{aux} + \Delta E_{load\ processing} \quad (2)$$

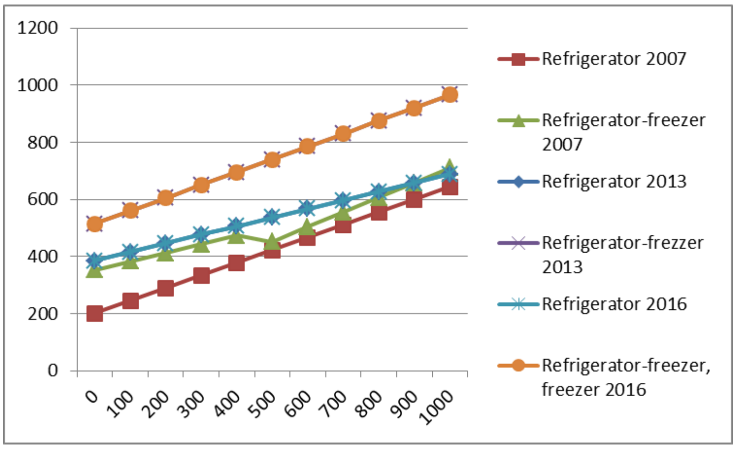

Figure 51 MEPS for refrigerator-freezer in Viet Nam

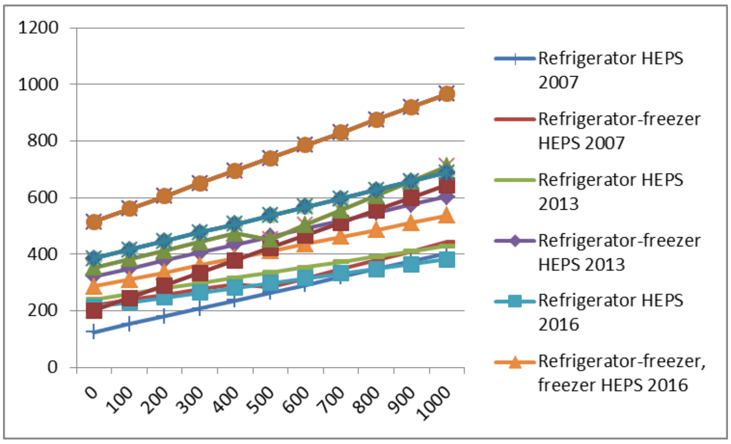

Figure 52 HEPS for refrigerator-freezer in Viet Nam

Table 29 Grade of energy efficiency in Viet Nam

R	Grade
R < 1,1	failed
1,1 ≤ R < 1,2	1
1,2 ≤ R < 1,4	2
1,4 ≤ R < 1,6	3
1,6 ≤ R < 1,8	4
R ≤ 1,8	5

As comparing these three versions for MEPS and HEPS benchmarks in Viet Nam, in addition to the promotion of the EE benchmark, they also harmonized domestic test standards with the new IEC 62552 and gave effect to TCVN 7829:2007 (ISO 15502:2005), TCVN 7829:2013 (IEC 62552:2007), and TCVN 7829:2016 (IEC 62552:2015), as shown in Table 30.

Table 30 Comparison of Test Conditions for refrigerator test standards

Test condition		TCVN 7829:2007 Ref. ISO 15502	TCVN 7829:2013 Ref. IEC 62552:2007	TCVN 7829:2016 Ref. IEC 62552:2015
1	Ambient temperature	30ºC	32ºC	32ºC
2	Temperature measurement method	Test package	Cylinder	Cylinder
3	Food freezer compartment temperature	Average -18ºC ± 0.5ºC	Average ≤ -18ºC	Average ≤ -18ºC
4	Fresh food compartment temperature	Average 3ºC ± 0.5ºC	Average ≤ 4ºC	Average ≤ 4ºC
5	Test period / Methods for determination of daily energy consumption (E_{daily})	From Defrost and end at 24h or 48h or 72h	Defrost to Defrost	Separate steady state + defrost term
6	Automatic ice maker	None	None	None
7	Anti-condensation heater	None	None	Done
8	Load processing test	None	None	Done
9	Volume	Gross	Cooled volume	Cooled volume

As Viet Nam implemented EE management in 2012, the refrigerator testing can only be carried out by a third party laboratory accredited by the Government. However, the manufacturers' laboratories are allowed to perform product inspection and apply the Grade labeling by their own reports, as the new version of EE management was implemented in 2016, as shown in Figure 53. It shows that the policy changes will have a major impact on EE management, and unpredictable risks will be encountered in the near future. Therefore, market supervision has become more important, but, it also creates a heavy burden. Therefore, VSQI needs to negotiate with the Government, manufacturers, and importers. After financing, the market supervision requires substantial funds based on the information of collected EE database and the post-market supervision, the organizational structure, and the tasks of VSQI must be adjusted as necessary to meet the future EE management.

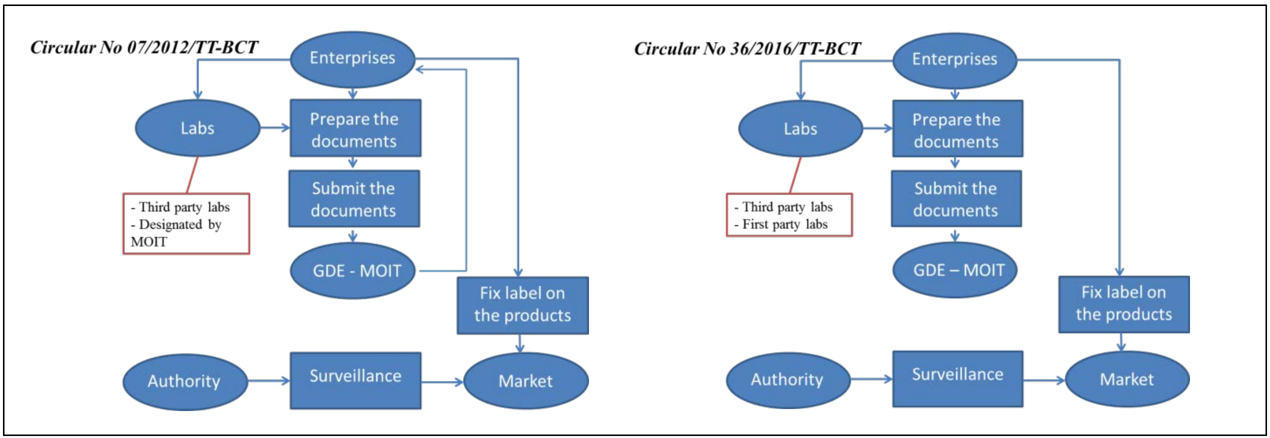

Figure 53 Policy changes for EE management in Viet Nam

3.4.5 Malaysia's Experience

The last speaker in this workshop was Mr Gan Chok Ser from MACRA (Malaysian Air Conditioning and Refrigerant Association). Malaysia's EE STAR rating was announced by the Minister of Energy, Green Technology and Water Malaysia on 3 May, 2014, "Amendment to the Electricity Regulations 1994" (also known as Electricity Revision (Amendment) Regulations 2013) and it incorporates the standards and requirements for the implementation and enforcement of the Minimum Energy Performance Standards for five items of domestic electrical equipment, which are: Refrigerators, Air-Conditioners, Televisions, Domestic Fans, and Lighting. It also makes it mandatory for four items of said equipment to be affixed with an energy rating label or a star rating label for lighting, and the efficiency value is required to be shown on the cover or box for the items.

MEPS in Malaysia specifies the minimum levels of energy performance that appliances, such as refrigerators, must meet or exceed before they can be offered for sale or used for commercial purposes. According to the Malaysian Standards Test Method MS IEC 62552:2011 (Household Refrigerating Appliances - Characteristics and Test Methods), single and double door refrigerators must have a 2 star rating. The requirements, as shown in Figure 54, are the star rating label for energy efficiency management in Malaysia for said five household appliances. Following MACRA's test study for refrigerator energy consumption during the EE Star Rates implementation, three categories can be divided by storage volume for comparison of annual electricity consumptions, including 200 to 299L, 300 to 399L, and 400 to 499L, as listed in Table 31.

The results show that the most effective way to reduce residential energy consumption is to use inverter-driven refrigerators and MEPS-compliant products. Therefore, MACRA will continue to assist the Government to promote EE management of Malaysia's electrical appliances, and also to assist manufacturers in product testing, issuance reports, verification, and registration. The number of star-rated funds promoted in recent years is shown in Figure

55, with a highest efficiency rating of 5 stars. There is a gradual increase in the number. At the end of the briefing, the speaker gave a detailed introduction to MACRA's recently expanded EE testing equipment, which introduction enabled delegates to better understand the process of the performance testing of household appliances and facilitated the promotion and implementation of energy efficiency management in various economies.

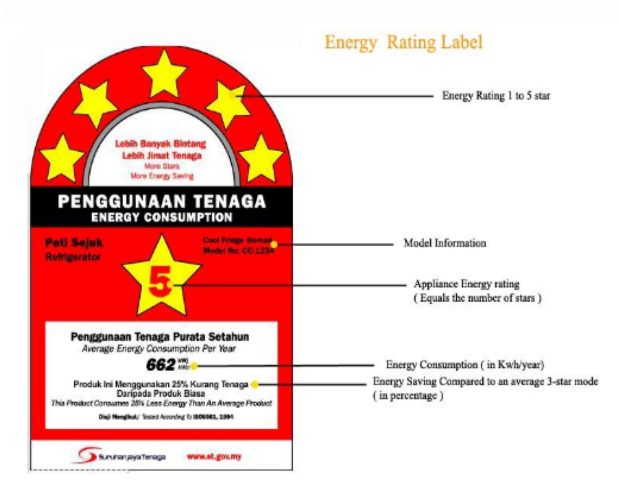

Figure 54 Energy efficiency label in Malaysia

Table 31 Test results of refrigerators in Malaysia’s Star Rating Program by MACRA

Effective storage volume / Energy consumption (kWh/yr)	200-299L	300-399L	400-499L
Highest energy consumption	445	484	526
Second highest energy consumption	318	343	380
Lowest energy consumption	263	336	376

Figure 55 Comparison of model numbers of refrigerators of star rated label in Malaysia

4. Discussion

Generally, there are four major aspects that serve to support substantial promotion of energy efficiency management programs, including (i) energy saving technology (ii) energy efficiency test procedures, (iii) energy efficiency standards and labels, and (iv) incentive programs (Wiel et al, 2005 and Bansal et al, 2011) as shown in Figure 56. These government policy instruments can be designed to achieve penetration of energy efficient technology and the corresponding products in the marketplace, and then to meet energy-saving goals. This project has completed the survey and research works with respect to EE promotion for refrigerators in the APEC region by using a questionnaire survey, EE technical reviews, and by hosting a technical seminar and two workshops as indicated in this report. All of the studied outcomes also involved said major aspects supporting EE management. This chapter summarizes the latest developments in EE technology, harmonization of test methods, EE standards and labeling, and some incentive programs based on Figure 56 and the outcomes of all of the studied works in this project, and then explores the methodology for improving the efficiency of marketing refrigerators.

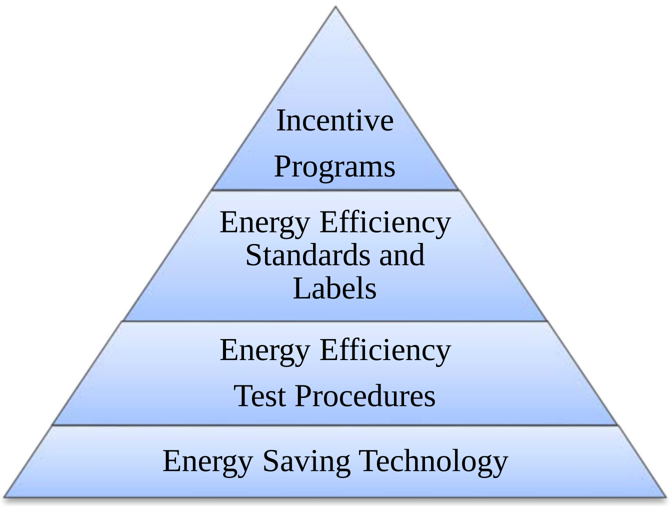

Figure 56 Structure of Energy Efficiency Management Program

A. Energy Saving Technology

Over the past two decades, significant efforts have been devoted to improving the energy efficiency of refrigerators in the APEC region. Some policy tools that have led to this improvement include energy labeling, high efficient appliance procurement, voluntary agreements, demand side management, and minimum energy efficiency standards. All of these policy implementations are based on available energy saving technologies. On the demand side, consumers are increasingly interested in the savings potential from energy efficient appliances. According to the CLAPS's study (Wiel et al, 2005), policy strategies that can help expedite the introduction of new technologies include:

- support for research and development to create new products or their components
- design (or revision) of energy-test methods to reflect and accommodate technical innovations
- organization of buyer demand to expand the market for available high-performing products and to induce manufacturers to introduce new products

As with the review study of energy-saving technologies for household appliances conducted by Bansal *et al* in 2011, energy savings can be realized by accelerating the introduction of new technologies into the market place by: 1) establishing stringent minimum energy performance standards, 2) implementing government initiatives for the promotion of energy efficient products, and 3) providing incentives to both manufacturers and consumers. Hence, energy-saving technology development and EE policy promotion must complement each other, especially in the early stages of the market transformation for high efficient products through energy conservation policies. This is also the focus point of this project.

According to the replies to the questionnaire, it is discovered that questions regarding the refrigerator market and the technology needed are not fully reported. However, EE management policies and test methods were clearly indicated. Perhaps most of the respondents are policy makers or are from executive agencies, who are not familiar with technology information. By hosting the Energy Saving Technology Seminar on 16 November, 2017 at Taipei City, this project completed the collection of the up-to-date technical information on the EE promotion of refrigerators, including smart appliance controls, test standard harmonization, refrigerant technology, high efficient compressors, inverter controls technology, PU foaming, thermal-fluid simulation, systems and designs. This report provides detailed technical knowledge as well as the surveyed information from available and accessible literature (ASHRAE, 2010, Bansal et al, 2003, Wiel et al, 2005, Bansal et al., 2011 and Belman-Floreset et al, 2015), which will be helpful to policy makers or the corresponding institution agencies to study and promote their respective benchmarks.

At the Workshop I held on 9 April, 2018, the USA expert speaker shared that both the average selling price and energy consumption of refrigerators have decreased by 70% and that the average equivalent volume has increased by more than 50% in the past 50 years. This outcome is consistent with the study by CLASP (Wiel et al, 2005) in 2005 - "Energy-efficiency standards are the primary reason that the average new refrigerators sold in the U.S. today use one-quarter the electricity of the average new refrigerator manufactured 30 years ago." The development of energy-saving technology can provide energy-saving benefits, and the reason for the cost reduction is likely the result of mass production. Unlike the Asian region's application of inverter-driven compressors to enhance energy efficiency of refrigerators, manufacturers in the USA usually choose performance enhancement of PU foaming material and opt to increase the wall thickness of refrigerators, as well as using high efficient AC compressors with fixed frequency. Japan's expert shared some experiences and considerations regarding potential technical improvements to meet the new target in FY2015 in Japan, including designs for cold air circulation, EE promotion for compressors, high density winding wire and interior permanent magnet for BLDC motors, and the application of vacuum insulation panels. Similar technology information was also proposed by Chinese Taipei at Workshop I.

At Workshop II, held on 11 September, 2018, the project invited speakers from manufacturers and testing institutions to share their practical experiences with EE promotion. Two experts from refrigerator factories in Chinese Taipei shared some ideas for product inspection of quality insurance and key component design in response to the upgraded EE benchmark in Chinese Taipei. As surveying some technical information from the USA and Europe, some traditional technologies are still important to improve EE for refrigerators, including high efficient AC compressors, refrigerants, PU foaming enhancement and thermal insulation, thermal leakage prevention, defrost mechanisms, system designs, and quality insurance. However, inverter control technology and VIP are welcomed in the Asia area, as VIPs were commercialized about twenty years ago in Japan. Although the costs for these two technologies is still relatively high, all of the expert speakers at Workshop II confirmed the EE potential for inverter-driven refrigerators, which will become mainstream for the high efficient market in the near future. As VIP is still expensive and the long-term stability of VIP has not yet been achieved, VIP can only be regarded as a temporary solution to improving the energy efficiency of refrigerators. The makers need to enhance the PU foaming performance, i.e., to reduce the thermal conductivity of PU foaming inside the walls of refrigerators, and keep up the inspection of quality insurance, regularly.

B. Energy Efficiency Test Procedures

The test standards comparison among different economies for household refrigerators and freezers was studied several decades ago, including all the domestic and international standards. Meier *et al* (1997) proposed criteria for a good test procedure:

(i) reflect actual usage condition;

(ii) yield repeatable, accurate results;

(iii) reflect the relative performance of different design options;

(iv) cover a wide range of models within a category;

(v) produce results that are easy to compare with other test procedures;

(vi) be easy to modify to accommodate new technologies or features; and

(vii) be inexpensive to perform;

Unfortunately, these goals usually conflict with each other (Mahlia and Saidur, 2010), and the previous studied efforts did not conform to a general EE test procedure for refrigerators until only a few years ago. In 2005, Wiel and McMahon (2005) suggested the adoption of an internationally recognized test procedure with a simplified version to lower costs and to avoid technological obstacles. The early international standards for refrigerators were published by ISO, such that ISO 8561 and ISO 7371 are the relevant standards for testing energy consumption of household refrigerator-freezers having two or more compartments. Subsequently, the ISO integrated the relevant refrigerator standards into ISO 15502:2005, which specifies the essential characteristics of household refrigerating appliances, factory-assembled and cooled by internal natural convection or forced air circulation, and established test methods for checking the characteristics.

In 2006, the IEC initiated a process towards converging, harmonizing, and widely sharing testing and labelling methodologies and procedures to overcome the not-negligible differences in regulations. Then, ISO 15502 (2005) was revised and harmonized previous standards and reissued these as IEC 62552:2007. In May 2013 the subcommittee released for comment a committee draft for voting prIEC 62552 (Edition 2) as the consensus basis for a globally acceptable procedure to test the performance and energy consumption of household refrigerating appliances, and finally adopted and published this in February 2015 as IEC 62552-3 Edition 1.

Following a review study of the results of APEC project EWG 04 2014A and the outcomes of the technical seminar and workshops, some developing economies, such as the ASEAN economies and Central & South America regions in the APEC region, not only need to establish an integral EE management system, but also need to strengthen the refrigerator industry technical capacities to achieve overall market efficiency improvement. In order to accelerate the refrigerator efficiency promotion, this project (EWG 07 2017) aimed to share successful experiences with the enhancement of refrigerator efficiency technology and EE management systems with developing economies. From the outcomes of the questionnaire study and the technical discussion at the 2^{nd} workshop in Thailand, most economies are also planning to adopt IEC 62552:2015 as their new refrigerator test method. Lastly, the presence of and the need for certain refrigeration technologies are indicated in most economies. Because different test methods create technical barriers to trade in the region, and to further improvement of energy efficiency, on the basis of the project results, EWG 07 2017 continuously encouraged APEC economies to adopt the new IEC 62552 as their test method, and to invite experts for training programs, and to organize Round Robin Test (RRT) among developing economies.

C. Energy Efficiency Standards and Labels

Energy-efficiency standards are procedures and regulations that prescribe the energy performance of manufactured products, sometimes prohibiting the sale of products that are less efficient than a certain minimum level (Zangheri et al, 2015). Energy-efficiency labels affixed to manufactured products to describe the product's energy performance give consumers the data necessary to make informed purchases (Zangheri et al, 2015). Through the hosting of two workshops in 2018, this project successfully collected practical examples of refrigerator EE standards and labels used by some economies, including the history of their implementation, the process of their revisions, the problems encountered, and the future development of such standards and labels. Among the invited economies participating in the workshops or the technical seminar, several economies have proposed data on the significant improvement of refrigerator efficiencies and shared experiences in the implementation of EE standards and labels, including the USA; Japan; China; New Zealand; and Chinese Taipei.

Other economies participating in the project's events have been actively going about revising or implementing their energy efficiency standards and labels in recent years, and have proposed plans for their future energy efficiency benchmarks, including Thailand; Viet Nam; Malaysia; and Indonesia. Although some economies did not attend the events, the economies planning to implement refrigerator energy efficiency standards will be increasing in numbers in the APEC region, according to the survey study of the questionnaire and the open literature gathered and prepared by this project.

D. Incentive Programs

Numerous studies have demonstrated that the penetration of energy-efficient products is far below the level that is cost-effective for energy consumers. Energy-efficiency policies seek to close this gap by identifying and addressing the barriers that prevent consumers from investing in energy-efficient equipment. The incentive programs are either direct government roll-outs with money raised through taxes or mandatory savings goals set for energy providers to reduce their customers' energy use (Stephanede et al, 2014). Survey study found an example wherein the U.S. refrigerator tax credit upstream program has been largely successful as shown where each extension of the program pushed the efficiency standard higher so that the next set of incentives would further increase the energy saved. One of the reasons for the program's success was the robust stakeholder involvement and education regarding how to participate in the program (Stephanede et al, 2014). Although the incentive program was not the focal point of this project, some expert speakers also shared experiences with incentive programs utilized to improve energy efficiency of refrigerators in the marketplace. Many economies have used government budgets to encourage customers to buy energy-efficient products through tax or subsidy incentive programs, and some other programs included the American Recovery and Reinvestment Act of 2009, U.S. state energy-efficiency programs, Japan's Eco-point Program, Mexico's PNSEE, U.S.'s PACE program, and South Korea's promotion of energy-efficient goods (Wiel et al, 2005 and Stephanede et al, 2014).

E. Methodology and Market Transformation by EE Standards

Following the study by CLASP in 2005, 'Standards shift the distribution of EE models of sold in the market upward by eliminating a baseline for programs that provide incentives for "beating the standard." Labels shift the distribution of EE models upward by providing information that allows consumers to make rational decisions and by stimulating manufacturers to design products that achieve higher ratings that the MEPS (Wiel et al, 2005), as shown in Figure 50. From the EE promotion experience shared by the USA's expert at Workshop I held in Washington, DC, under the suitable situation of economic scale, improving energy efficiency may not cause costs to rise, as the improvement in manufacturing technology and mass production scales are in line with economic benefits, the price of the product can be significantly reduced, and the US electricity consumption for refrigerators has been reduced in the past 50 years. The average retail price of refrigerators is over 70%. Refrigerator standards in the USA are the most dramatic example of emerging technology and the ratcheting effect (Wiel et al, 2005).

Similar energy conservation efforts for refrigerators were also found in Japan by the experience shared at Workshop I. For the results and expected energy efficiency improvement of Japan's Top Runner Program, the target FY2010 for residential use is a 43.0% improvement from the FY2005 level compared to the initial expectation of 21.0% and the target for FY2021 is expected improvement of 22.0% based on the FY2014 level. Japanese manufacturers routinely meet "voluntary targets" even though Japanese regulations make no stipulation for enforcement or penalties for not meeting these targets.

There are still many followers in the APEC region, and they have already reached their targets for energy-saving performance, such as Australia; China; Hong Kong, China; Korea; Singapore; New Zealand; and Chinese Taipei. Some economies are working diligently to improve the energy efficiency of refrigerators, including Thailand, Viet Nam, Malaysia, Philippines, and Indonesia. After the discussion at the workshops, economy representatives requested knowledge dissemination or training workshops for structural procedures of EE management, including pre-mark registration, testing and certification, and marketing surveillance following some of the practical systems, i.e., the USA Energy Star Program.

In some cases, policy makers will change energy efficiency management measures at the request of stakeholders or business groups. For example, institutional laboratories designated by the governments were originally required to conduct performance tests for mandatory standards. Then, the manufacturer's laboratories were allowed to conduct the tests for their own products. For policy changes in EE management, it is necessary to study or gather more information for best practices on adaptation for policy changes to energy efficiency regulations.

5. Conclusion

This project distributed a questionnaire surveying the energy efficiency management and technology development issues for refrigerators to the APEC members to seek their participation. In total, the ten responses all from APEC economies were received, namely from Viet Nam; Indonesia; Thailand; Malaysia; New Zealand; Korea; Hong Kong, China; Japan; Singapore; and Chinese Taipei. With regard to their geographical distribution, the vast majority of respondents were concentrated in East Asia region and one was from New Zealand. According to the responses, it is discovered that questions regarding the refrigeration market and the technology needed are not fully reported, whereas questions regarding EE management policies and test methods are clearly indicated. Regarding the refrigeration market, refrigerator-freezers are the most commonly-used refrigerating appliance in all the responding economies. Referring to the presented information of the invited expert speakers, the sales of refrigerators of sizes above 500 liters is the highest proportion of refrigerator-freezers with 3-doors in Chinese Taipei. Multi-door refrigerator-freezers are also becoming popular in China. The mainstream type in Japan is multi-door refrigerator-freezers, in Korea the most popular is side-by-side doors, and in Southeast Asia the most common is the two-door refrigerator-freezer. In terms of EE management, all of the responding economies have implemented EE programs with a market surveillance program. Most economies are planning to adopt IEC 62552:2015 as their new refrigerator test method. Lastly, the presence of and the need for certain refrigeration technologies are indicated by most economies. In the needs of refrigerator EE technology, the types of refrigerants HFC-134a and R-600a, variable-speed refrigeration system technology, and VIP are the main requirements indicated in the responses to the questionnaire.

To gather international experts in EE refrigerators / freezers to discuss the latest technology developments for refrigerators / freezers in energy savings, the working group successfully hosted a self-funding refrigerator seminar ‘Energy Saving Technology Seminar for Refrigerator / Freezer Energy Efficiency Improvements in APEC Region’ on 16 November, 2017 at the Howard Plaza Hotel in Chinese Taipei. The project also invited experts from developing economies in the APEC region to participate in the seminar and the 1st technical expert group meeting on 17 November, 2017 to discuss the outcomes of the previous survey study and the case studies of this project, including the economies of Indonesia; Malaysia;

Thailand; and Viet Nam. Six APEC economies participated in this event including China; Indonesia; Malaysia; Chinese Taipei; Thailand; and Viet Nam. Forty attendees from domestic manufactures and laboratories participated in this seminar. Five important topics were presented and discussed at the seminar, including smart appliance design, testing standard harmonization, environmental trends for refrigerants, novel high EE compressors, and systems for refrigerators, which subjects were consistent with the trends surveyed by the project team from the open (available and accessible) literature published in the past two decades. Detailed technical information has been summarized in this report to provide all the members of the APEC region to use and improve the EE of refrigerators related to refrigerators under EE regulations in the near future. The project team also retained the personal contact information of all of the experts at the technical seminar and workshops. If the APEC members require additional detailed information or technology resources, they can contact the project team directly for the same.

During December 2017 to April 2018, the project team finished the work items for case studies of refrigerators / freezers designs and implementation under energy efficiency regulations, including (i) adopted feasible energy saving technologies and policies, (ii) completed the investigation report for the results of the case studies on refrigerators / freezers designs and implementation under energy efficiency regulations on 30 April, 2018, (iii) successfully hosted Workshop I on 9 April, 2018 during the 51st APEC EGEE&C meeting in Washington, DC, USA, (iv) reported the research results to the workshop, and (v) after workshop I, gathered representatives from each economy to the 2nd technical expert group meeting to discuss the resolutions of the case studies.

At Workshop I, four expert speakers were invited to share the histories and benefits of policy implementation processes among APEC economies with successful experiences with refrigerator EE promotion. In total, eighteen attendees from ten APEC economies participated in this event, including China; Indonesia; Japan; Malaysia; Mexico; New Zealand; Chinese Taipei; Thailand; Viet Nam; and USA. This project also invited five active participants from travel eligible economies in the APEC region to attend workshop I and the 2nd technical expert group meeting to discuss the outcomes of the previous survey study and the case studies of this project. The case studies for policy implementation for EE promotion of refrigerators included the energy-saving technology development or introduction, the relevance of energy-saving technologies and EE benchmarks, the designs of EE management programs, market surveillance methods, laboratory test procedures and product certification, efficiency improvements, stakeholder’s meeting processes, and subsidies.

There were some highlight outcomes to note in Workshop I. In the past 30 years in the United States, the average selling price and energy usage of refrigerators have dropped by more than 70%, and the average equivalent volume of each refrigerator has increased by 50%.

In Chinese Taipei, by successful promotion of energy labeling following MEPS in 2011, the high-efficiency product market share increased from 3% to 97% in five years. Although Japan's Top Runner program is voluntary, the Government guides the manufacturers to comply with and implement this policy tool, greatly improving the energy efficiency of refrigerators. The refrigerator efficiency improvement policies implemented in Australia and New Zealand have also achieved good results. These research results are helpful to develop future energy efficiency management and benchmarking for other APEC economies. This event provided a refrigerator energy saving knowledge sharing platform and refrigerator network integration of EGEE&C to provide energy saving design information.

In order to conduct a study of successful EE management programs and to identify the best practices for approaching energy efficiency improvement methodologies and outcomes, this project invited experts from refrigerator manufacturers and testing institutions to share practical cases in energy efficiency improvement for refrigerators under EE regulations for Workshop II. The topics for EE promotion of refrigerators included energy-saving technology development, energy efficiency management, and other incentives to explore mechanisms for improving the efficiency of marketing refrigerators. Eight expert speakers and 45 attendees from 12 economies, including China; Hong Kong, China; Indonesia; Japan; Malaysia; Mexico; New Zealand; Singapore; Chinese Taipei; Thailand; Viet Nam; and USA participated in this workshop on September 11, 2018 at Chiang Mai, Thailand. The project team also assisted in the nomination and travel reimbursement for four active participants from travel eligible economies.

Workshop II integrated energy policy and refrigerator EE technology development, and the experts shared many practical pathways and related efforts to improve their product efficiencies under high efficiency energy requirements. TECO’s new refrigerator model from Chinese Taipei uses a new smart control technology to detect the frequency of the door-opening and to learn from usage habits, such as when users get up in the morning, prepare breakfast, go to work, return home, cook dinner, and sleep. With such intelligent learning, the refrigerators can enter sleep mode, which is a super energy-saving mode, to meet the needs of the home. Smart controls were also implemented by using a mobile APP for temperature control, food management, downloading recipes, ordering merchandise, and providing daily power consumption for the new intelligent refrigerator proposed by Panasonic from Chinese Taipei. In the past ten years in China, the energy efficiency of refrigerators has been greatly improved, and the terminal prices have been declining year-by-year. Similar to the USA’s experience, energy efficiency standards are driving a market shift to high efficient products. China rewards high-efficiency products by eliminating inefficient products with MEPS and adopting the labeling scheme with EE Grade 1, Grade 2, and the top-runner program. Experts from Thailand, Viet Nam, and Malaysia shared the implementations of EE policies for refrigerators, and some of the new energy saving technology for refrigerators is applied. They also introduced the processes of standard harmonization, which follow the new version of IEC 62552 and they offered some valuable suggestions for policy tools and testing laboratory management in the APEC region. By holding Workshop II, the economies with successful experiences with refrigerator EE promotion shared their histories and benefits of policy implementation processes and energy-saving technology developments. After the workshop, the team gathered representatives from each economy to the technical expert group meeting to discuss the resolutions with respect to the case studies. Workshop II actually expanded the knowledge regarding EE management and energy conservation application in the APEC region.

The project has successfully disseminated EE management and energy saving technology knowledge mainly through the workshops and the seminar. However, it is difficult to review and understand such a high volume of information regarding technical and EE management measures in such a short period of time. Moreover, the mechanisms for successful EE management experiences are quite complicated, and cannot be fully understood in the period during which the workshops and seminars were held. This problem could likely be solved by offering additional training courses to those economies that seek assistance.

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ANNEX I

WORKSHOP ON CASE STUDIES OF REFRIGERATORS/FREEZERS DESIGN AND IMPLEMENTATION UNDER ENERGY EFFICIENCY REGULATION (EWG 07 2017A)

AGENDA

ONE-DAY WORKSHOP: 9 April 2018
VENUE: Embassy suites, Hilton Hotel, Washington DC, USA
MODERATOR: Project Overseer, Project Manager

08:50 – 09:10	Workshop Registration
09:10 - 09:20	Welcome address
09:20 - 09:30	Opening address
09:30 - 10:00	Introduction to the EWG 07 2017A Project and its Implementation Status. – Ms Nicole Yun-Tzu Guo, Industrial Technology and Research Institute (ITRI), Chinese Taipei.
10:00 - 10:30	Experience sharing of USA on EE promotion of refrigerator /freezer under energy efficiency regulation (Pt.1) – Ms Stephanie Johnson, Department of Energy, USA
10:30 - 11:00	*Group photo and Coffee Break*
11:00 - 11:30	Experience sharing of Chinese Taipei on EE promotion of refrigerator /freezer under energy efficiency regulation – Mr Tony Wen-Ruey Chang, Industrial Technology and Research Institute (ITRI), Chinese Taipei
12:00 – 14:00	Lunch
14:00 - 14:30	Experience sharing of Japan on EE promotion of refrigerator/freezer under energy efficiency regulation – Mr Hiroki Yoshida, Ministry of Economy, Trade and Industry, Japan
14:30 - 15:00	Experience sharing of New Zealand on EE promotion of refrigerator/freezer under energy efficiency regulation – Mr Eddie Thompson, Energy Efficiency & Conservation Authority, New Zealand
15:00 – 15:30	*Coffee Break*
15:30 - 16:00	Conclusion for Case Studies of Refrigerators/Freezers Design and Implementation under Energy Efficiency Regulation – By Project Manager and Technical Woking Group Member Closing of the Workshop
16:00 – 17:00	Technical Expert Group Meeting

ANNEX II

WORKSHOP ON REFRIGERATOR/FREEZER ENERGY EFFICIENCY IMPROVEMENT IN APEC REGION: REVIEW OF EXPERIENCE AND BEST PRACTICES (EWG 07 2017A)

AGENDA

ONE-DAY WORKSHOP: 11 September 2018
VENUE: Convention Hall 01, Le Méridien Chiang Mai Hotel, Chiang Mai, Thailand
MODERATOR: Project Overseer

08:30 – 09:00	**Workshop Registration**
09:00 - 09:10	Welcome address
09:10 - 09:20	Opening address
09:20 - 09:40	• Introduction to the EWG 07 2017A Project and its Implementation Status. • The Recent Development of Energy Efficiency Technology and Management for Refrigerator/Freezer in APEC Region. – By Technical Working Group Member
09:40 - 10:10	*Group photo and Coffee Break*
10:10 - 10:40	Experience sharing of Thailand on Refrigerator/Freezer Energy Efficiency Improvement • Energy Efficiency for Refrigerator(MEPS and HEPS) Under Energy Conservation Act in Thailand – Dr Supachai Sampao, Department of Alternative Energy Development and Efficiency, Ministry of Energy, Thailand • Experience sharing on refrigerator energy efficiency promotion – Mr Pawatt Suwannakut, Electrical and Electronics Institute, Thailand
10:40 - 11:30	Experience sharing of Chinese Taipei on Refrigerator/Freezer Energy Efficiency Improvement – Mr Tony Wen-Ruey Chang, Industrial Technology and Research Institute (ITRI), Chinese Taipei • Go Smart Life ECO by TECO – Mr Chi-Tseng Peng, Household Appliances Group, TECO Electric & Machinery Co, Ltd, Chinese Taipei • Panasonic Green Design – Mr Heng-Chun Lee, Refrigerator R&D Department AP Development Center, Appliances Domain Business, Panasonic Co Ltd, Chinese Taipei
11:30 - 12:00	Experience sharing of China on Refrigerator/Freezer Energy Efficiency Improvement – Dr LI, Pengcheng, China National Institute of Standarization, China
12:00 – 13:30	Lunch
13:30 - 14:00	Experience sharing of Viet Nam on Refrigerator/Freezer Energy Efficiency Improvement – Ms Doan Thi Thanh Van, Viet Nam Standards and Quality Institute (VSQI), Viet Nam
14:00 - 14:30	Experience sharing of Malaysia on Refrigerator/Freezer Energy Efficiency Improvement – Mr ChokSer Gan, Cooling Innovation Sdn Bhd Malaysian Air-Conditioning & Refrigeration Association (MACRA), Malaysia
14:30 – 15:00	*Coffee Break*
15:00 - 16:00	Panel Discussion and Conclusion for Review of Experience and Best Practices – By Project Manager and Technical Working Group Member Closing of the Workshop
16:00 – 17:00	Technical Expert Group Meeting