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Dramatic Effects of Temperature Variations on Signal Quality and Cost Budget Through Different Optical Indoor and Local Area Smart Home Networks Applications

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Abstract**—** *This paper has deeply investigated the network system capacity for different transmission network applications as well as the spectral losses, and the dispersion effects are parametrically investigated over wide range ranges of the set of affecting parameters. It is taken into account the estimation of the total cost of the fiber cable cost for different silica and plastic optical fibers. Network system bit rate capacity can be estimated based on different transmission techniques for different network applications. Signal bandwidth, signal to noise ratio, bit error rate, and fiber cable cost are the major interesting performance parameters for different fibers in our study. The results are validated against published simulation work with plastic clad silica (PCS) and polymethyl metha acrylate (PMMA) and show very good results.*

Index Terms— Fiber to the home, Plastic fibers, Silica fibers, NRZ, Classical technique, and Shannon technique.

I. INTRODUCTION

Technological changes and innovations in telecommunications are causing subscriber's to demand for more multimedia services in their homes. To improve network capacity for indoor environment, various techniques have been used to increase data rates and enhance data transmission. These techniques involve several transmission media which also have their advantages and disadvantages. Fiber to the home (FTTH) appears to be an emerging technology that could enable optimum broadband service delivery up to the end users [1-3]. FTTH allows for larger bandwidth and faster delivery speeds, which are essential for modern triple play deliveries in which access providers offer video, data, and telephony services.

Dispersion is the main factor limiting the transmission capacity of optical fiber communication systems by causing inter-symbol interference (ISI) and increasing bit error rate (BER) of the system. Two types of dispersion called as chromatic dispersion and polarization mode dispersion (PMD) occur in single mode optical fibers. Chromatic dispersion is due to the wavelength dependence of the speed of light transmitted in the optical fiber. Chromatic dispersion is composed of material dispersion and waveguide dispersion. Material and waveguide dispersions can be positive or negative and they can even cancel each other. Furthermore, there are various methods compensating chromatic dispersion effects in high bit rate long haul communication systems [4, 5].

Traffic demand has been increasing steadily in the last few years. In order to support this increasing traffic demand the optical links between the main cities, which are typically terrestrial links with hundreds of kilometers operating at 10 Gb/s per channel, have to be upgraded. A solution for the upgrading of these links is to increase the bit rate per channel to 40, 80 or even to 160 Gb/s. The major operators intend to use the already installed cables to support these high speed systems, which is not surprising, as the most cost effective solution usually resides in upgrading the terminal equipment keeping the link unchanged. However, the majority of the cables in the field contain G.652 fibers, which have a high level of chromatic dispersion in the conventional spectral window, where erbium doped fiber amplifiers provide the optical gain. In high bit rate systems, in order to cope with tight restrictions imposed by chromatic dispersion, it is mandatory to use dispersion compensation techniques. Several devices and schemes have been proposed to provide an accurate management of the chromatic dispersion, over a large spectral window. However, even with wavelength per wavelength careful tuning, these systems still present an unstable behavior when tested in the field subjected to extreme environmental conditions [6, 7].

II. BASIC THEORETICAL APPROACH

The core refractive index, n, as a function of the operating signal wavelength, λ, is defined through the Sellmeier equation which has the mathematical form [8]:

$$n=\sqrt{A+\frac{B\lambda^2}{\lambda^2-C}+\frac{D\lambda^2}{\lambda^2-E}} \qquad (1)$$

The single model graded index is modeled for most popular materials used in fabrication optical fiber, which namely Cytop and vycor glass (96.4% SiO_2 , 3% B_2O_3, 0.5% Al_2O_3, 0.1% Miscellaneous Traces) Where its Sellmeier coefficients of different materials based optical fibers are listed in Table 1..

Table 1. Coefficients of materials based optical fibers [5, 8, 9].

Coefficients	Cytop	Vycor glass
A	3.4325647	1.2754213
B	0.6576543 (T/T_0)	0.8271916 (T/T_0)
C	0.0324567	0.01653107
D	1.21345 (T/T_0)	0.9384236 (T/T_0)
E	150	100

The propagation constant, β, for graded index optical fibers can be given by the mathematical formula:

$$\beta=\sqrt{\frac{V^2}{2\Delta n\,R^2}-\frac{6\,V}{R^2}} \qquad (2)$$

Where R is the fiber core radius in μm, Δn is the relative refractive index difference between core and cladding, while V is the normalized frequency or V number which is given by the following expression [8]:

$$V=\frac{2\pi R}{\lambda}\sqrt{n^2-n_{cl}^2} \quad (3)$$

Where n_{cl} is the fiber cladding refractive index and is equal to (n-Δn). As well as the total dispersion of a fiber is expressed as temporal broadening per unit length of the fiber per unit width of the light source used. However, the total dispersion parameter, D_T, is can be modeled as [8]:

$$D_T=D_m+D_w \quad (4)$$

Where D_m, and D_w are the material and waveguide dispersion respectively which are modeled as:

$$D_m=-\frac{\lambda}{c}\left(\frac{d^2n}{d\lambda^2}\right) \quad (5)$$

$$D_w=-\frac{V^2}{2\pi c}\left(\frac{d^2\beta}{dV^2}\right) \quad (6)$$

Where c is the free space speed of light ($3\text{x}10^8$ m/sec), ($d^2n/d\lambda^2$) is the second derivative of refractive index can be expressed as listed in Refs. [8, 9]. Moreover, ($d^2\beta/dV^2$) is the second derivative of graded index propagation constant equation can be shown in [8]. The Fiber bandwidth characterizes the transmission capacity of a fiber. For the graded index Gaussian-shaped pulses for multiple number of users [10]:

$$BW=\frac{0.44}{N\tau} \quad (7)$$

Where τ is the total pulse broadening due to total dispersion effects, which can be given by [9]:

$$\tau=\Delta\lambda\, D_T\, L \quad (8)$$

Where Δλ is the spectral linewidth of the optical source in nm, L is the optical fiber length. As well as the signal to noise ratio (SNR) can be expressed as a function of optical signal to noise ratio (OSNR) as the following [9]:

$$SNR=OSNR\left[\frac{1}{1+\left(\frac{\alpha}{G_{opt.}}\right)^2}\right] \quad (9)$$

Where α is the optical signal loss, and $G_{opt.}$ is the optimum optical amplifier gain. While OSNR can be given by [9]:

$$OSNR=\frac{\lambda P_i}{2\,h\,c\,BW} \quad (10)$$

Where P_i is the input optical signal power, h is the Planck's constant. Where the transmission bit rate at the receiver side can be modeled with Shannon technique by the following mathematical relation [9, 10]:

$$B_{Rx.Side}=BW\log_2(1+SNR) \quad (11)$$

Therefore, the bit error rate (BER) in relation to signal to noise ratio can be estimated by the following formula [11]:

$$BER=\left(\frac{2}{\pi\, SNR}\right)\exp\left(-\frac{SNR}{8}\right) \quad (12)$$

Based on the clarified data in Refs. [12, 13], the relation between optical loss (α) with operating signal wavelength (λ), ambient temperature, and fiber length (L) for both Vycor glass fiber and Cytop plastic fiber can be given by:

$$\alpha(Vycor\ glass)=0.652\ Exp(-\frac{\lambda}{LT})-0.0231\,Exp\left(\frac{LT}{\lambda}\right)^2+0.0648\,Exp\left(\frac{-\lambda}{LT}\right)^3 \quad (13)$$

$$\alpha(Cytop)=3.687\,Exp\left(\frac{-\lambda}{LT}\right)-0.754\ Exp\left(\frac{LT}{\lambda}\right)^2+0.525\ Exp\left(\frac{-\lambda}{LT}\right)^3 \quad (14)$$

The system transmission bit rates are given with classical transmission technique by the following formula [14]:

$$B_R(Classical)=\frac{5\text{x}\,10^{17}e^{-\alpha L}}{5+\tau L} \quad (15)$$

As well as the transmission bit rate within non return to zero code (NRZ) can be given by [15]:

$$B_R(NRZ)=\frac{0.7}{\tau} \quad (16)$$

The basic formula for a typical optical link is an exponential decaying function as function of the fiber length as the following expression [14]:

$$P_R=P_i\,e^{-\alpha L} \quad (17)$$

Where P_i is the input optical power. As well as the loss power can be estimated by:

$$P_{Loss}(\%)=\frac{P_i-P_R}{P_i} \quad (18)$$

Moreover according to Ref. [14], the estimated total cost of fiber cable system can be estimated by:

$$C_T=\Gamma C_c+\beta C_e+\gamma C_t+\delta C_i \quad (19)$$

Where C_c is the fiber cable cost, C_e is the submerged electronics cost, C_t is the terminal & power feed and terminal stations cost, C_i is the installation cost, and r, β, γ, and δ are the estimated parameters as mentioned in Ref. [14], that is r between 1.5 and 2, the value of β to be between 1.5 and 2, γ=1, and 0.4 ≤ δ ≤ 0.7. As well as the previous costs are also estimated for fiber cable system as mentioned in Ref. [14], that is C_c=103 M$, C_e=78 M$, C_t=6 M$, and C_i=10 M$. based on Eq. (18) and Ref. [14], the fiber cable cost can be deduced by the following formula:

$$C_c(Max.)=\frac{375\,\text{x}10^4\,\alpha}{N\,\ln\left(\frac{P_i}{P_R}\right)}\quad(\$) \quad (20)$$

$$C_c(Min.)=\frac{282\,\text{x}10^4\,\alpha}{N\,\ln\left(\frac{P_i}{P_R}\right)}\quad(\$) \quad (21)$$

III. THEORETICAL RESULTS AND PERFORMANCE ANALYSIS

This study has deeply investigated the signal transmission characteristics analysis and operation performance efficiency of both vycor glass and Cytop plastic optical fibers in different optical short and local area transmission network applications under wide range of the affecting operating parameters as listed in Table 2. We compared our theoretical results by using both vycor glass and Cytop plastic optical fibers with his simulation result by using PCS and PMMA optical fibers.

Table 2: List of operating parameters used in mathematical model [1, 2, 7, 8]

Operating Parameter	Value and Units
Room temperature, T_0	27 ^{0}C
Ambient temperature, T	-100 ^{0}C to 100 ^{0}C
Refractive index difference, Δn	0.02
Fiber core radius, R	20 μm
Input optical power, P_i	100 mW
Optical wavelength, λ	1.3 μm
Optimum amplifier gain, $G_{opt.}$	5 dB
Fiber length, L (Indoor applications)	500 m
Fiber length, L (Local area applications)	10 km
Source spectral linewidth, $\Delta\lambda$	0.1 nm
Number of users, N	128

Based on the mathematical equations analysis and list of operating parameters, the clarified figures from 1 to 18 can be discussed as the following results:

i) Figs. (1, 2) have assured that Shannon bit rate at the receiver side decreases for both vycor glass and Cytop plastic fibers with increasing ambient temperature variations for both indoor and local area network applications. It is observed that vycor glass has presented the highest bit rate in compared with PCS as well as it is indicated that Cytop plastic fiber has presented the highest bit rate in compared with PMMA at the same operating conditions.

ii) As shown in Figs. (3, 4) have indicated that signal to noise ratio decreases for both vycor glass and Cytop plastic fibers with increasing ambient temperature variations for both indoor and local area network applications. It is observed that vycor glass has presented the highest signal to noise ratio in compared with PCS as well as it is indicated that Cytop plastic fiber has presented the highest signal to noise ratio in compared with PMMA at the same operating conditions.

iii) Figs. (5, 6) have demonstrated that bit error rate at the receiver side increases for both vycor glass and Cytop plastic fibers with increasing ambient temperature variations for both indoor and local area network applications. It is observed that vycor glass has presented the lowest bit error rate in compared with PCS as well as it is indicated that Cytop plastic fiber has presented the lowest bit error rate in compared with PMMA at the same operating conditions.

iv) As shown in Figs. (7-10) have indicated that both channel bit rate with using NRZ code and Classical technique decrease for both vycor glass and Cytop plastic fibers with increasing ambient temperature variations for both indoor and local area network applications. It is observed that vycor glass has presented the highest bit rate in compared with PCS as well as it is indicated that Cytop plastic fiber has presented the highest bit rate in compared with PMMA at the same operating conditions. as well as transmission bit rate with using NRZ code has presented its maximum values in compared to classical technique.

v) Figs. (11, 12) have demonstrated that received power at the receiver side decreases for both vycor glass and Cytop plastic fibers with increasing ambient temperature variations for both indoor and local area network applications. It is observed that vycor glass has presented the highest received power in compared with PCS as well as it is indicated as well as it is indicated that Cytop plastic fiber has presented the highest received power in compared with PMMA at the same operating conditions.

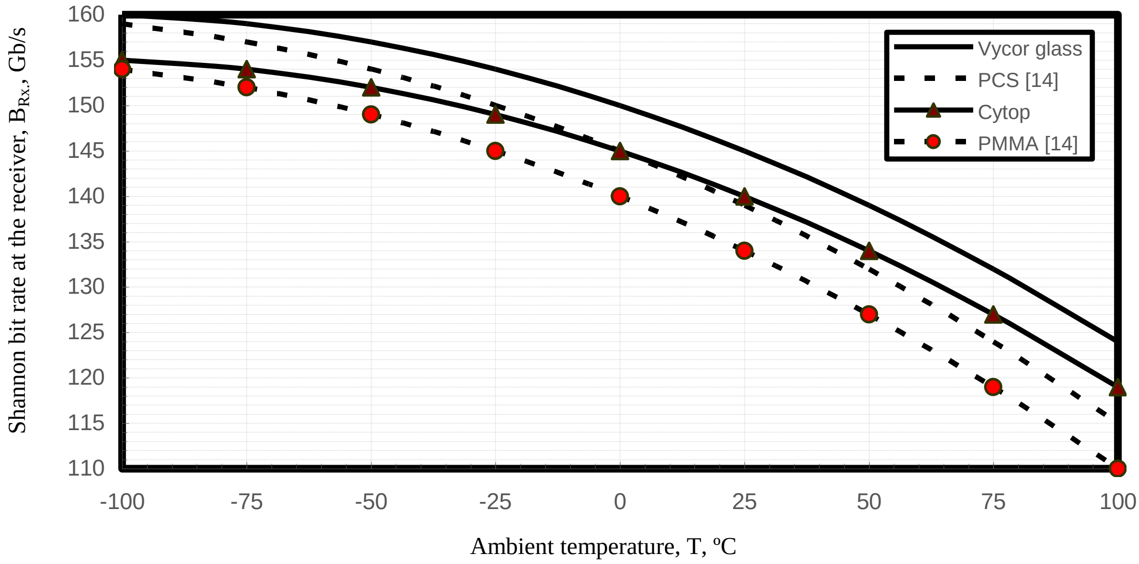

Fig. 1. Shannon bit rate at the receiver side against ambient temperature for indoor network applications based different optical fibers at the assumed set of the operating parameters.

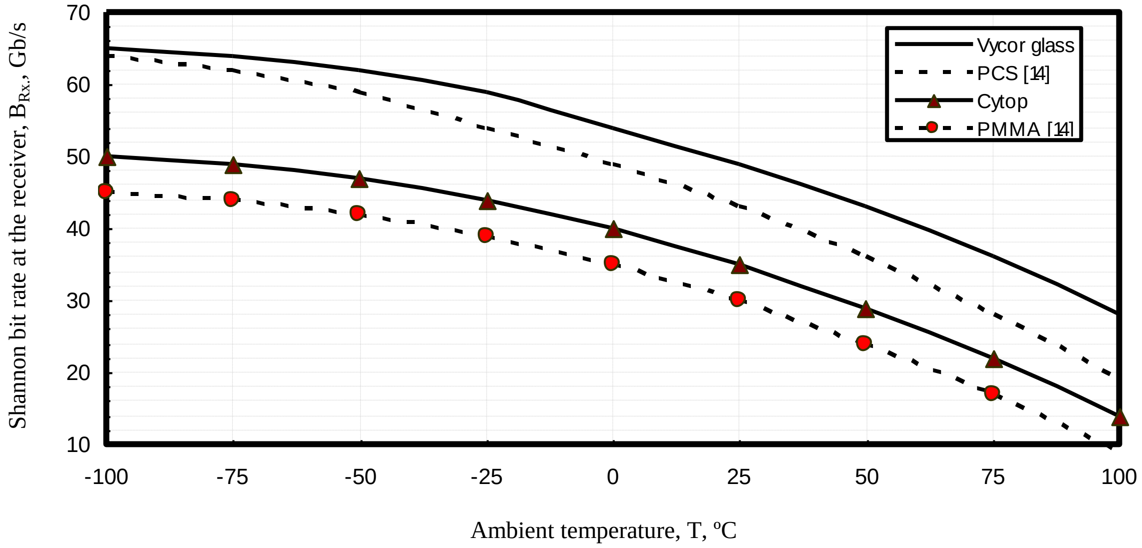

Fig. 2. Shannon bit rate at the receiver side against ambient temperature for local area network applications based different optical fibers at the assumed set of the operating parameters.

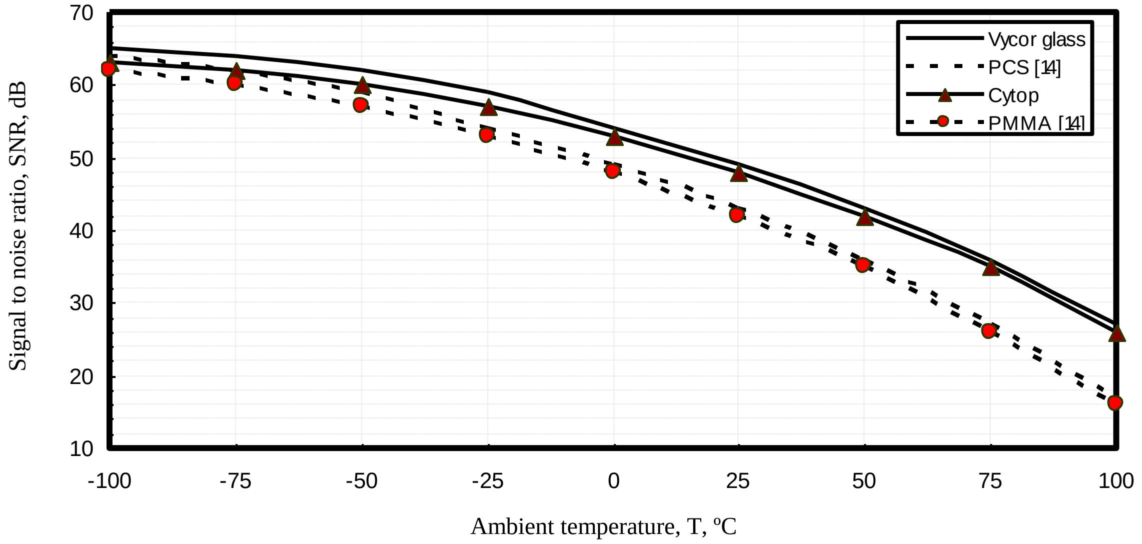

Fig. 3. Variations of Signal to noise ratio at the receiver side against ambient temperature for indoor network applications based different optical fibers at the assumed set of the operating parameters.

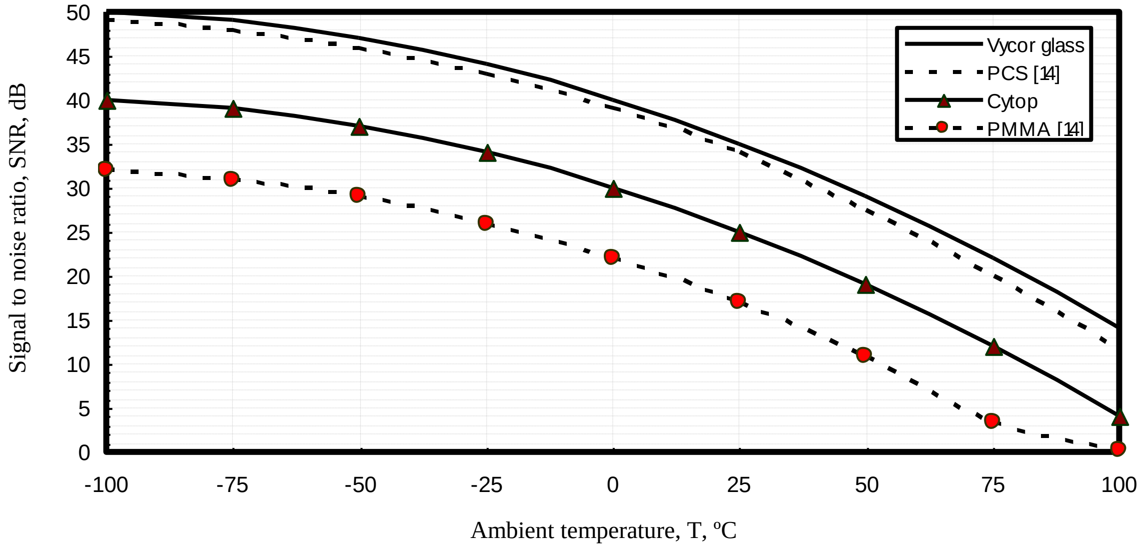

Fig. 4. Variations of Signal to noise ratio at the receiver side against ambient temperature for local area network applications based different optical fibers at the assumed set of the operating parameters.

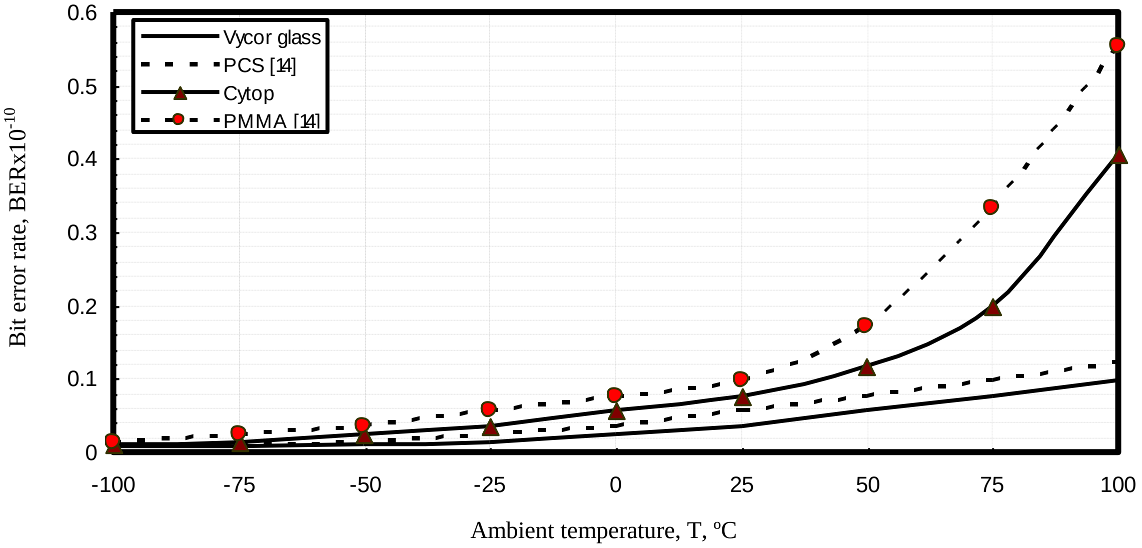

Fig. 5. Variations of bit error rate at the receiver side against ambient temperature for indoor network applications based different optical fibers at the assumed set of the operating parameters.

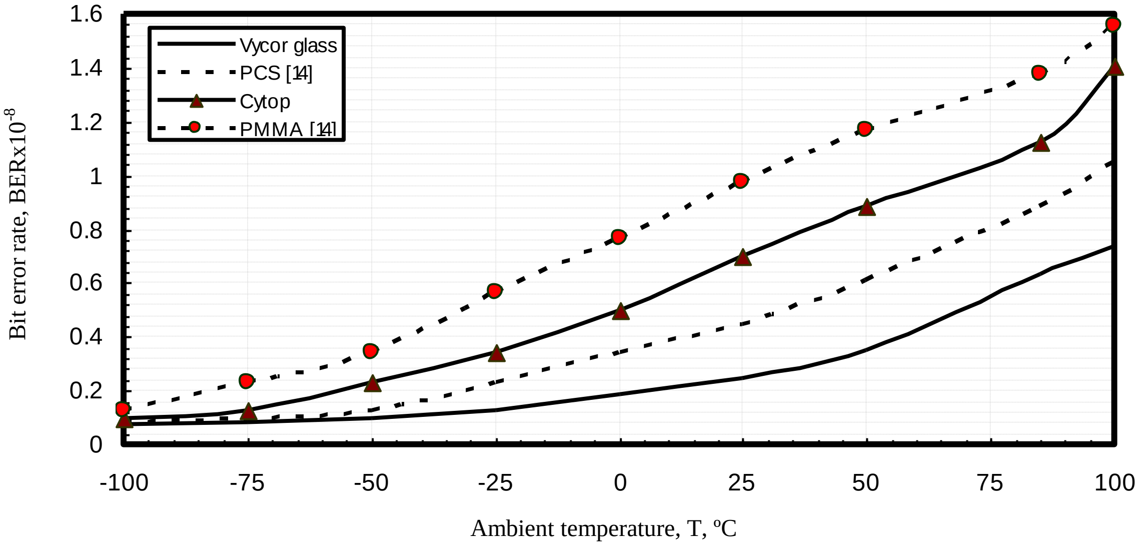

Fig. 6. Variations of bit error rate at the receiver side against ambient temperature for local area network applications based different optical fibers at the assumed set of the operating parameters.

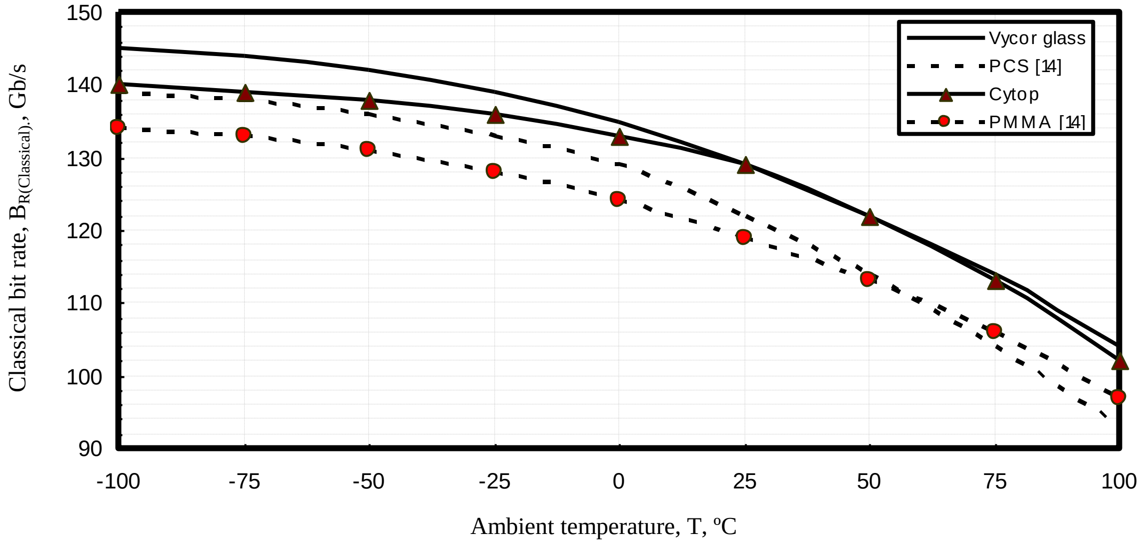

Fig. 7. Classical bit rate at the channel against ambient temperature for indoor network applications based different optical fibers at the assumed set of the operating parameters.

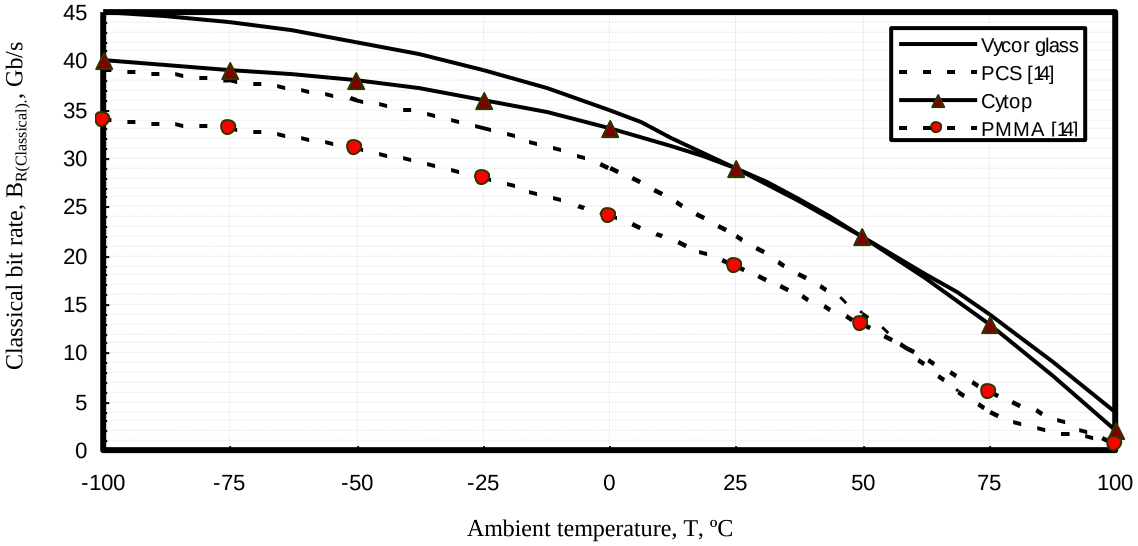

Fig. 8. Classical bit rate at the channel against ambient temperature for local area network applications based different optical fibers at the assumed set of the operating parameters.

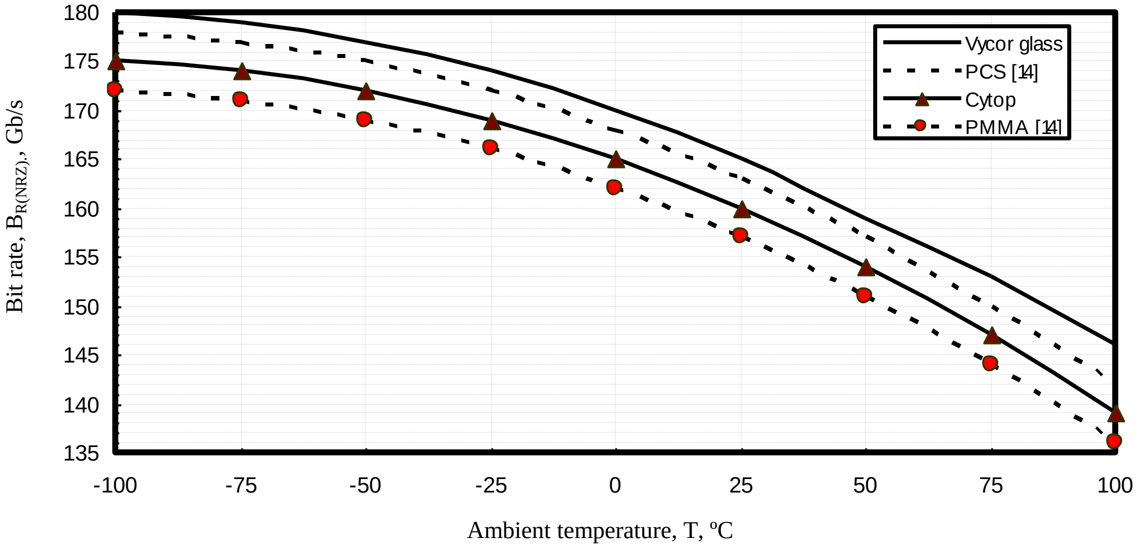

Fig. 9. Bit rate at the channel with NRZ code against ambient temperature for indoor network applications based different optical fibers at the assumed set of the operating parameters.

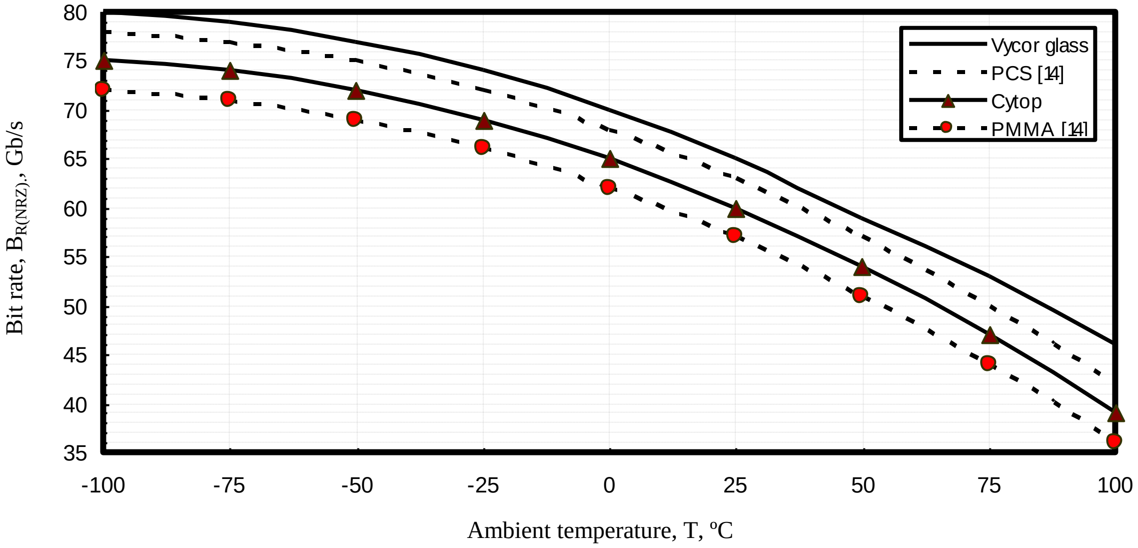

Fig. 10. Bit rate at the channel with NRZ code against ambient temperature for local area network applications based different optical fibers at the assumed set of the operating parameters.

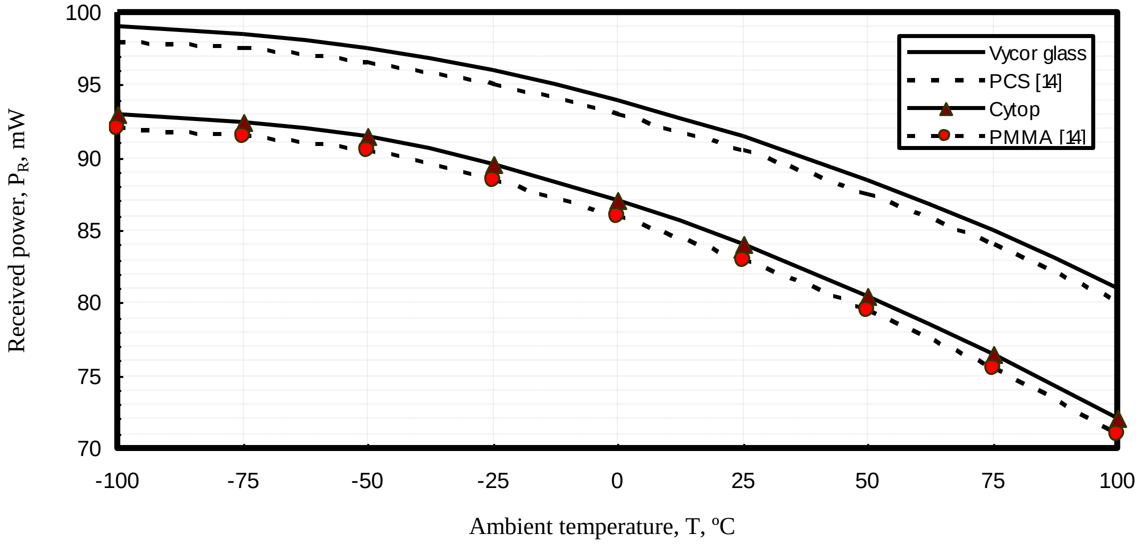

Fig. 11. Received power in relation to ambient temperature for indoor network applications based different optical fibers at the assumed set of the operating parameters.

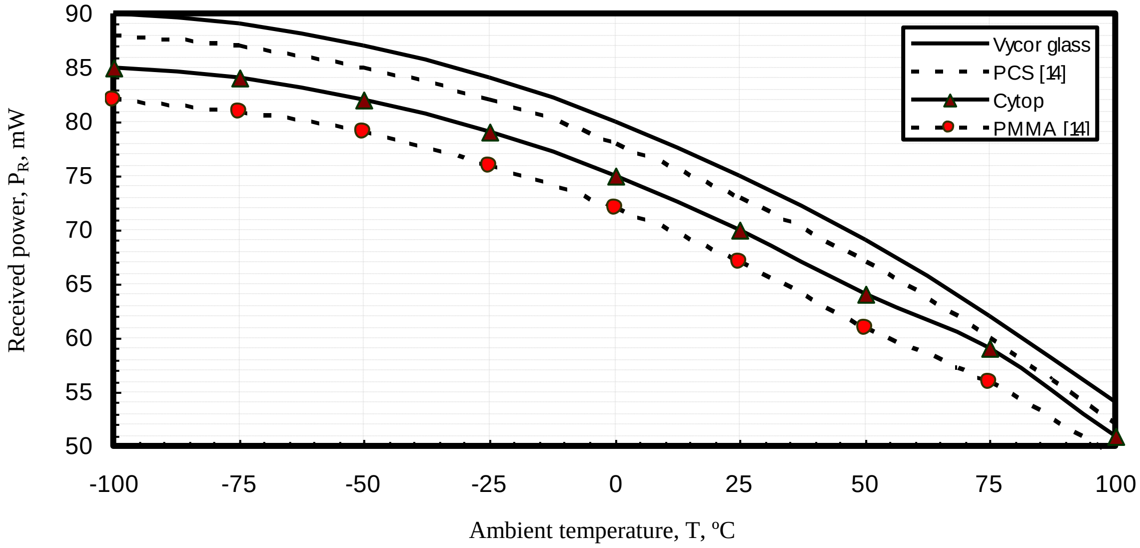

Fig. 12. Received power in relation to ambient temperature for local area network applications based different optical fibers at the assumed set of the operating parameters.

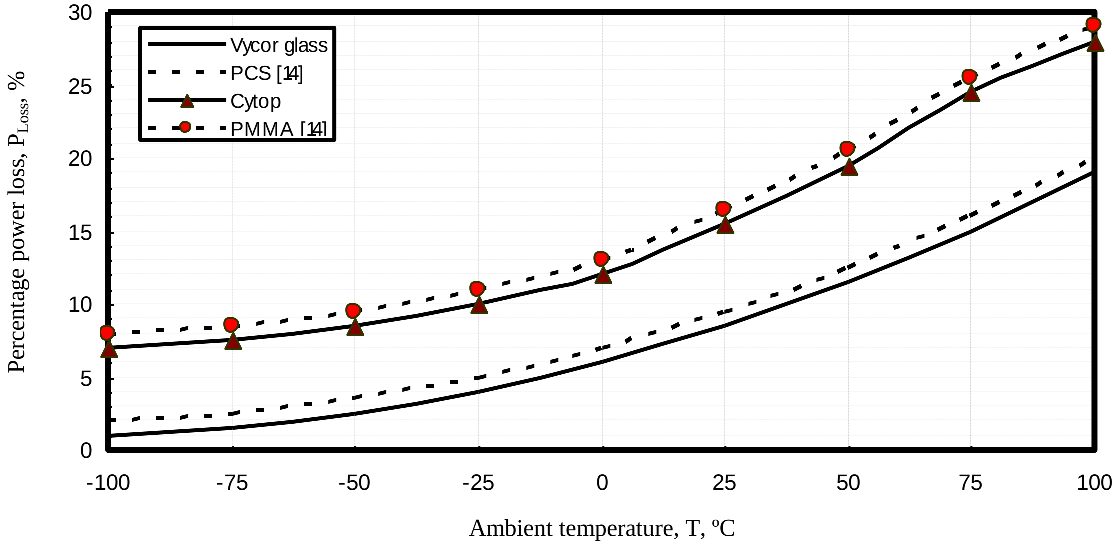

Fig. 13. Percentage power loss in relation to ambient temperature for indoor network applications based different optical fibers at the assumed set of the operating parameters.

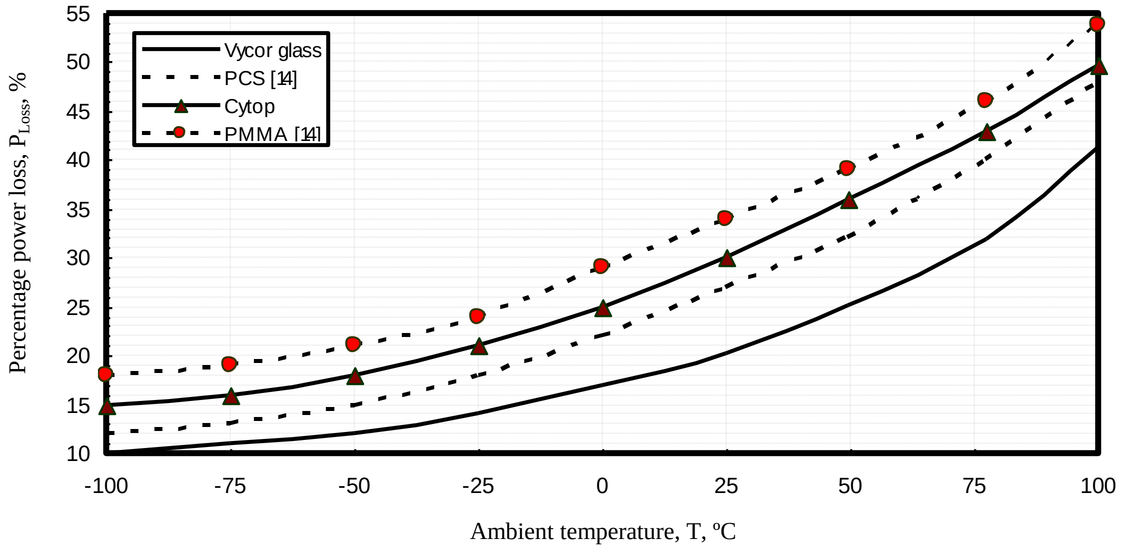

Fig. 14. Percentage power loss in relation to ambient temperature for local area network applications based different optical fibers at the assumed set of the operating parameters.

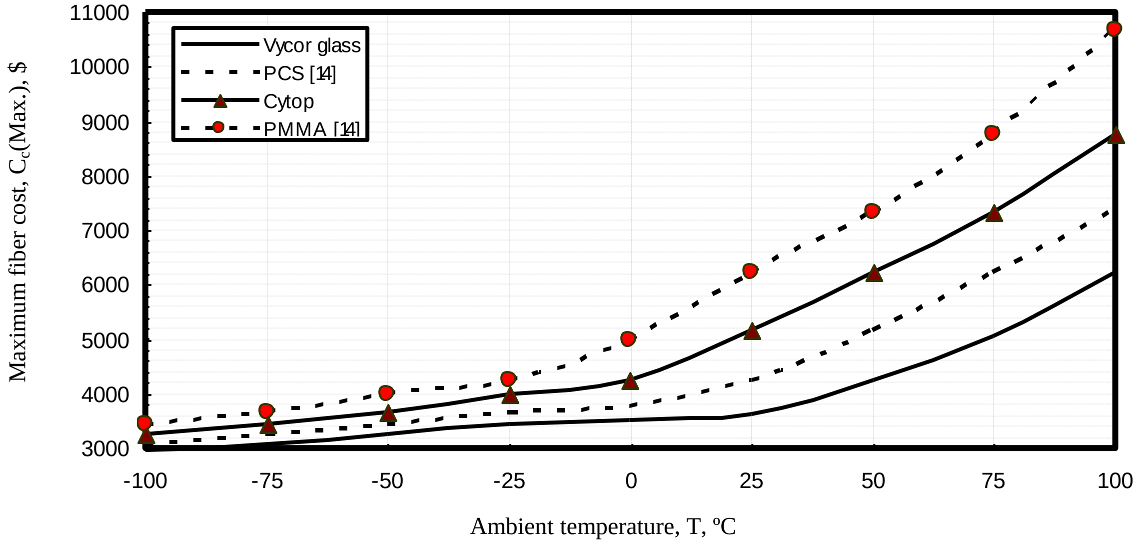

Fig. 15. Maximum fiber cable cost versus ambient temperature for indoor network applications based different optical fibers at the assumed set of the operating parameters.

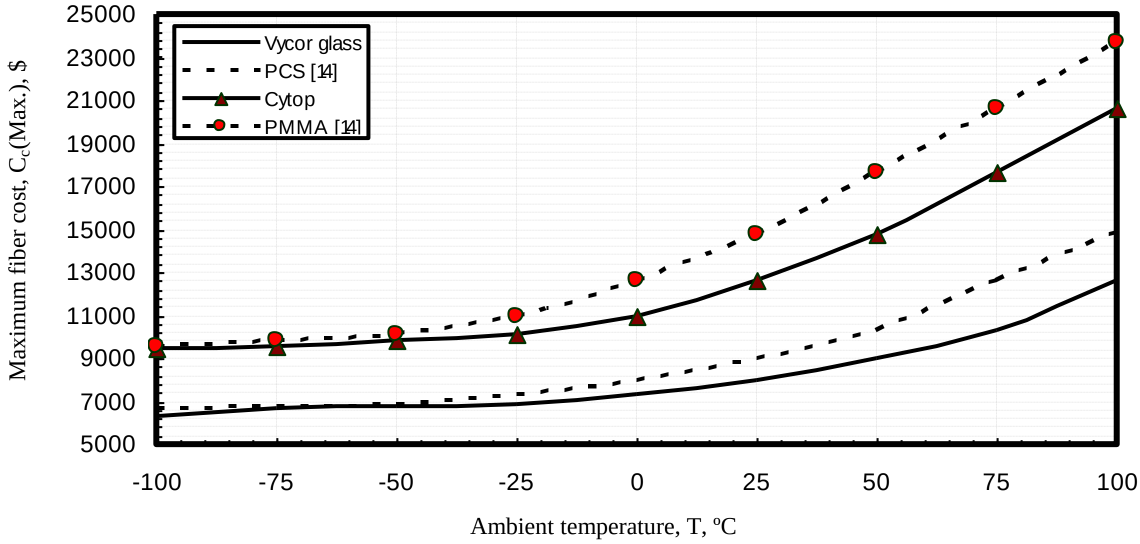

Fig. 16. Maximum fiber cable cost versus ambient temperature for local area network applications based different optical fibers at the assumed set of the operating parameters.

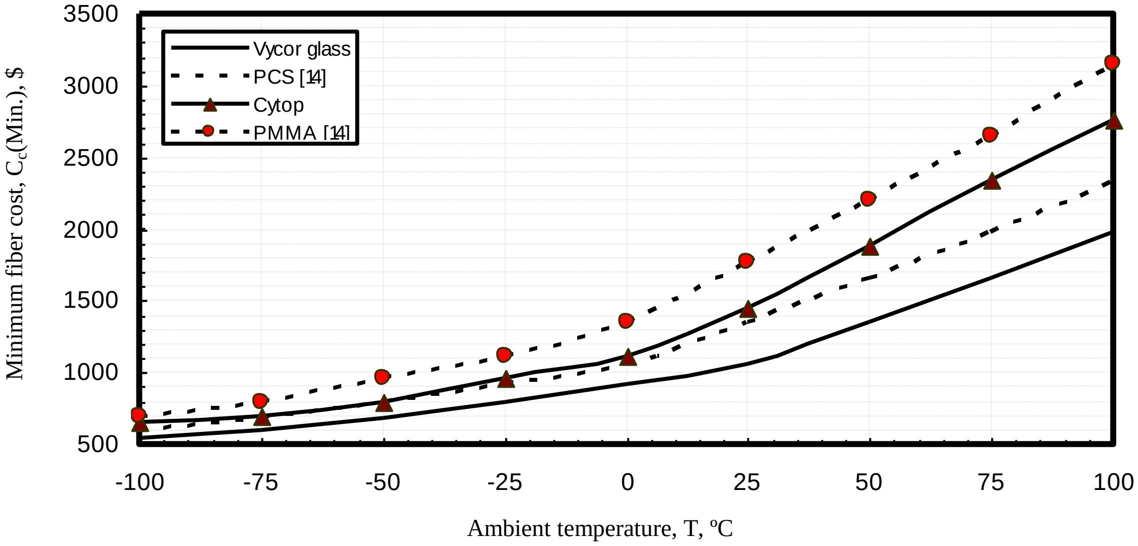

Fig. 17. Minimum fiber cable cost versus ambient temperature for indoor network applications based different optical fibers at the assumed set of the operating parameters.

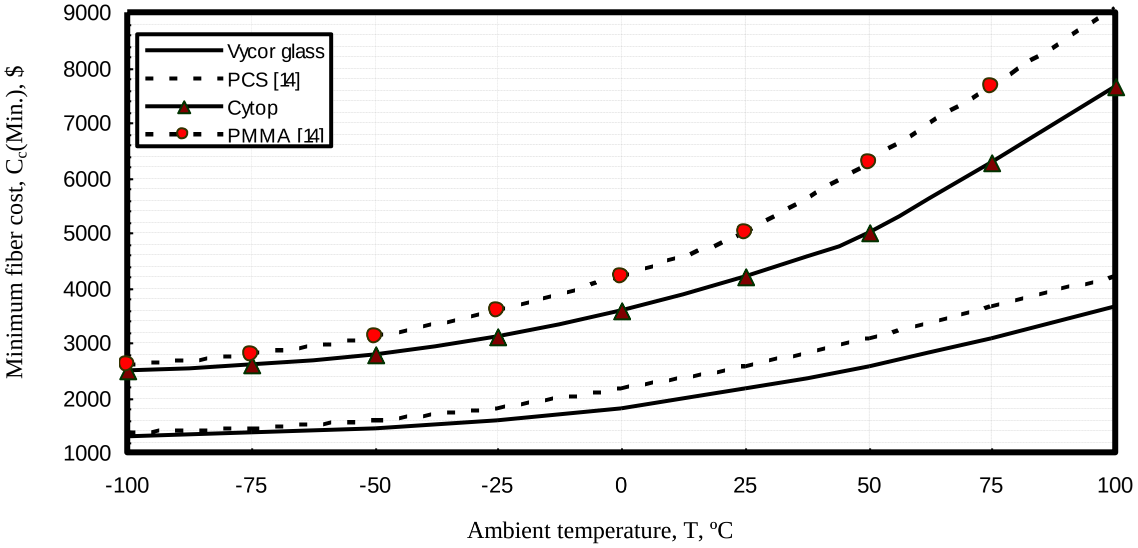

Fig. 18. Minimum fiber cable cost versus ambient temperature for local area network applications based different optical fibers at the assumed set of the operating parameters.

vi) As shown in Figs. (13, 14) have assured that percentage power loss at the receiver side increases for both vycor glass and Cytop plastic fibers with increasing ambient temperature variations for both indoor and local area network applications. It is observed that vycor glass has presented the lowest percentage power loss in compared with PCS as well as it is indicated as well as it is indicated that Cytop plastic fiber has presented the lowest percentage power loss in compared with PMMA at the same operating conditions.

vii) Figs. (15-18) have demonstrated that maximum and minimum fiber cable cost budget increases for both vycor glass and Cytop plastic fibers with increasing ambient temperature variations for both indoor and local area network applications. It is observed that vycor glass has presented the lowest maximum and minimum fiber cable cost budget in compared with PCS as well as it is indicated that Cytop plastic fiber has presented the lowest maximum and minimum fiber cable cost budget in compared with PMMA at the same operating conditions.

IV. CONCLUSIONS

In a summary, we have deeply investigated signal quality and cost budget through different optical indoor and local area smart home network applications under temperature variations. It is theoretically found that the dramatic effects of temperature variations on signal to noise ratio, received power, and bit rate degradation. As well as it is observed that bit error rate, percentage power loss, and fiber cable cost budget extremes increase with increasing temperature variations. Moreover it is found that the harmful dramatic effects on local area network in compared with indoor network applications. We have compared our results by using vycor glass and Cytop plastic fibers with his simulation results by using plastic clad silica and polymthhyl metha acrylate. Our results have gained optimum solutions for both indoor and local area network applications under the same operating conditions.

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Authors Profile

Dr. Ahmed Nabih Zaki Rashed was born in Menouf city, Menoufia State, Egypt country in 23 July, 1976. Received the B.Sc., M.Sc., and Ph.D. scientific degrees in the Electronics and Electrical Communications Engineering Department from Faculty of Electronic Engineering, Menoufia University in 1999, 2005, and 2010 respectively. Currently, his job carrier is a scientific lecturer in Electronics and Electrical Communications Engineering Department, Faculty of Electronic Engineering, Menoufia university, Menouf 32951.

His scientific master science thesis has focused on polymer fibers in optical access communication systems. Moreover his scientific Ph. D. thesis has focused on recent applications in linear or nonlinear passive or active in optical networks. His interesting research mainly focuses on transmission capacity, a data rate product and long transmission distances of passive and active optical communication networks, wireless communication, radio over fiber communication systems, and optical network security and management. He has published many high scientific research papers in high quality and technical international journals in the field of advanced communication systems, optoelectronic devices, and passive optical access communication networks. His areas of interest and experience in optical communication systems, advanced optical communication networks, wireless optical access networks, analog communication systems, optical filters and Sensors. As well as he is editorial board member in high academic scientific International research Journals. Moreover he is a reviewer member in high impact scientific research international journals in the field of electronics, electrical communication systems, optoelectronics, information technology and advanced optical communication systems and networks. His personal electronic mail ID (E-mail:ahmed_733@yahoo.com). He has supervised four PhD students and three MSc. students successfully and four Ph. D students and Seven MSc. students are currently pursuing their research under guidance. His published paper under the title **"High reliability optical interconnections for short range applications in high performance optical communication systems"** in Optics and Laser Technology, Elsevier Publisher has achieved most popular download articles in 2013.

Eng. Fatma Mohammed Aref Mahmoud Houssien was born in cairo city, Egypt in 5 April 1979. Received the B.Sc., and M.Sc. scientific degrees in the Electronics and Communications Engineering Department from Faculty of Engineering, Zagazig University in 2000, and 2012 respectively.

Currently, she is an electronics and communications engineer on the Operation and Maintenance of the Transmission Sector for the Middle and East Delta in Telecom Egypt. She is over ten years working in Transmission Sector for the Middle and East Delta in Telecom Egypt and contributed in many projects during execution, operation, and maintenance for Alcatel-Lucent, Nortel Networks, Siemens Products, Cisco Networks and ZTE Switches. Currently, she gets the DWDM Optical Devices Course Training from Alcatel-Lucent University, France. Her scientific master science thesis has focused on Local Area Optical Communication Networks especially via utilizing Polymer Optical Fibers.

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